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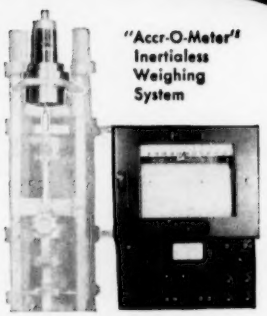

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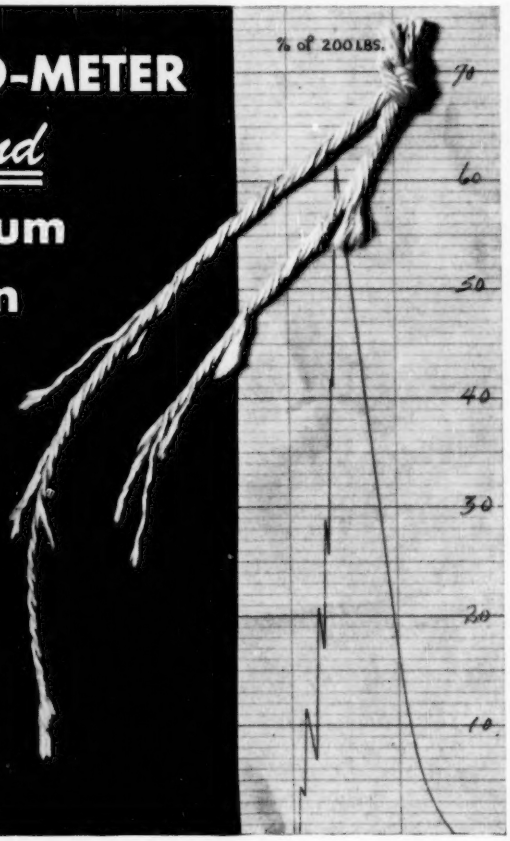

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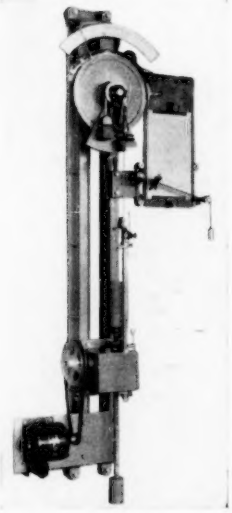

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TEXTILE RESEARCH JOURNAL

VOL. XXIII, NO. 2 February, 1953

Relationship Between Various Surface Properties of Wool Fibers*

Part I: Methods for Estimating Wool Fiber Modification

Joel Lindberg †

Institute for Applied Textile Research, Gothenburg, Sweden

Abstract

Wool fibers were steeped in alcoholic potash for different periods of time. The mechanical properties and swelling properties of these fibers were investigated, and the results obtained indicate that the potash treatments do not influence these properties. The Allwörden reaction was studied, and the results obtained show that the reaction time for the characteristic bubbles to appear is determined by the reaction rate between the chlorine and the keratin of the wool fiber. The epicuticle of the fibers, however, must be intact. It is further shown that the results of most staining reactions are dependent upon the properties of the epicuticle.

Introduction

Recent research on the morphology of wool fibers has disclosed that they, as well as other animal hairs, are covered by a thin layer which differs greatly in chemical composition from the underlying protein substance [22]. It has been suggested that this new morphological component be called the *epicuticle*, and this name is used herein when referring to this membrane [21]. The epicuticle can be isolated from the rest of the fiber in several ways. The bulk of the fiber can be dissolved in an appropriate reagent—*e.g.*, sodium sulfide—and the epicuticle, which is more resistant to the reagent, will remain intact. Another method is to dissolve the substance beneath the epicuticle, and remove the epicuticle by mechanical means—*e.g.*, shaking the fibers in water [17]. In both cases fragments of the epicuticle are obtained as a dispersion in water. These fragments may then be studied, preferably with the electron microscope. However, it is claimed that it is possible to use the phase-contrast microscope for this purpose [2, 23, 39]. By using shadowing techniques in the preparation of the specimen for study with the electron microscope, the thickness of the fragments can be estimated to be between 50 and 250 Å. [16, 22].

Very little is known about the chemical composition

* This series of papers (Parts I–IV) constitutes a thesis for the degree of Doctor of Technology, Chalmers University of Technology.

† Director of Research.

of the epicuticle. It is very resistant to acids, alkalis, and oxidizing and reducing agents. It is insoluble in common solvents. A few attempts to make chemical and x-ray analyses have been reported [10, 15, 37, 38, 39]. The results indicate that the epicuticle has a structure different from that of ordinary wool keratin, but some investigators (Lagermalm and Gralén) have stressed that it is very difficult to obtain an epicuticle specimen free from impurities; consequently, it is difficult to interpret the results obtained from these investigations.

It has been proven definitely that the epicuticle constitutes the surface layer of the fiber. Before it was isolated and observed in the electron microscope the presence of a membrane was suggested by Müller [28, 39] from the nature of Allwörden's reaction. Later, it was shown by Lindberg [17], and also by Schuringa and Algera [35], that the membranes responsible for the results obtained in Allwörden's reaction are identical with the epicuticle. The epicuticle is already present on the fiber when the fiber separates from the root sheath down in the follicle [36], and is consequently a morphological component. It is not a layer of extraneous matter formed afterwards.

Since the epicuticle forms the surface layer of the fiber, it is obvious that physicochemical properties such as friction and surface tension depend upon the nature and condition of the epicuticle. By a closer study of these and other surface properties it should be possible to gain some knowledge about the general structure of the epicuticle. The properties mentioned above are of great technological importance in wool processing, and have great bearing on the behavior and serviceability of wool fabrics. It is, therefore, valuable to know how the epicuticle will be affected by different conditions prevailing during the processing and use of wool fabrics.

Much is already known of these properties of wool from experience and previous research work, and a short survey of the properties of practical importance that may be related to the condition of the epicuticle is given by Lindberg *et al.* [21] and Gralén [10]. A more detailed investigation of the following properties is reported here—namely, frictional properties, including felting of top and its tensile strength, wettability, scourability, rate of sorption of acids and dyes, and also some tests for damage, including stress-strain properties, swelling, Allwörden's reaction, and staining reactions. For all experiments the same lot of wool was used, and samples from this lot were subjected to treatments known from previous experiments to have some effect on the epicuticle.

Pretreatment of Material

A 64's Australian wool was chosen as the experimental material. It is very difficult to make an unbiased sampling from the raw wool fleece, and therefore the material was taken from the worsted process in the top stage immediately after combing. Due to the blending action during carding, gilling, and combing, the material was considered sufficiently homogeneous to facilitate the sampling procedure.

The raw wool was scoured according to a solvent-scouring method using kerosene in open vessels with mechanical agitation. No additional scouring with water was used. Thus, the material had not been exposed to water previous to its treatment in the laboratory.

Pieces of 40 cm. length were taken from different parts of the top material. These pieces were randomized and divided into a number of groups corresponding to the number of pretreatments used. The first lot was not subjected to any treatment at all. The second lot was extracted with diethyl ether at room temperature. The wool was immersed in about 25 times its own weight of diethyl ether, kept there for 10 min., removed, and squeezed. This was repeated four times, while each time a fresh volume of ether was taken. Finally, the solvent was evaporated at room temperature. The third lot was first extracted with diethyl ether and then with ethyl alcohol (96%) at 50°C in the same manner as with diethyl ether. The alcohol was evaporated at 70°C overnight.

Freney and Lipson [7] have shown that if wool is treated with alcoholic potash, it is not only rendered nonfelting to a certain extent, but is also changed as regards its wettability, rate of sorption of dyes, etc., without showing any change in its mechanical properties. Their results indicate that only the surface of the wool fiber is modified. It has also been found that similar treatments affect the structure of the epicuticle, as revealed by examination with the electron microscope [16]. The alcoholic potash treatment was therefore used in this case to produce varying degrees of modification in the fiber surface. All samples that were to be treated in alcoholic potash were first extracted in ether and al-

cohol as described above and the wool was conditioned at 65% R.H. before the treatment. The wool was then immersed in 100 times its weight of a solution containing 2 g. KOH in 96 ml. ethyl alcohol (100%) and 4 ml. water. Three different lots were treated for 15 sec., 4 min., and 15 min., respectively. Immediately after removing the wool from the alcoholic potash solution it was put into a solution containing 1 ml. conc. H_2SO_4 in 96 ml. ethyl alcohol (100%) and 4 ml. water. After a few minutes steeping in this solution the wool was rinsed in distilled water and dried at 70°C overnight. By preparing all the experimental material before proceeding with the experiments, a more uniform treatment was obtained.

Some Methods for Estimating Wool Fiber Modification

When wool fabrics are processed and subsequently used, the fibers may be subjected to various conditions which can affect their physicochemical properties to different degrees. Although the exact relationship is not known, it generally can be said that fabric behavior is very much dependent upon fiber properties. Much work has therefore been done to find some simple methods whereby a change in the physicochemical properties of fibers can be detected. All these methods are generally referred to as "tests for wool fiber damage." The term "damage," however, implies that the wool fiber is of less value as a textile fiber, and since there are modifications that, in fact, improve the fiber for certain end-uses—*e.g.*, nonfelting treatments—the term "modification" is preferred here.

There are physicochemical properties or groups of properties which have certain influences on fabric behavior. These properties may be altered independently by various treatments. Hence, it is very unlikely that any one test for damage can present sufficient knowledge for conclusions to be drawn as to all phases of wool fabric behavior. Several tests must be used, each test being specific for one or several related properties. For instance, a staining test may show a modification of only the fiber surface, whereas the measurement of swelling may not reveal any information on this property. On the other hand, modification of surface properties may not noticeably influence the mechanical properties of the fabric. It is therefore necessary that all conventional tests for wool modification be critically examined in order to prevent wrong conclusions from being drawn from them.

It is beyond the scope of this paper to give a comprehensive survey of the vast amount of literature on this subject. Meeuse *et al.* published such a survey [24], and recommended certain tests for the detection of fiber modification and also for the determination of the cause of the modification. In general, their recommendations have been adopted in this paper.

The following tests for wool fiber modification were studied: (*1*) determination of stress-strain properties of single fibers; (*2*) determination of swelling; (*3*) Allwörden reaction; (*4*) staining reactions.

The main purpose of this investigation was to see if the different pretreatments used in the present experiments for modifying the surface properties of the fiber affect bulk properties such as swelling and stress-strain characteristics. The second purpose was to find the relationship between the four tests mentioned above and the physicochemical properties, which will be discussed in later papers in this series.

It should perhaps be pointed out that most of the methods suggested in the literature are generally not interpreted in terms of physicochemical properties. A positive result of a staining reaction, for instance, may be said to indicate a modification of the fiber by alkali, but nothing can be inferred from this as to the particular property that is affected by this modification.

Stress-Strain Properties

Of the various approaches to the measuring of a fiber's mechanical properties, the load-elongation curve (Figure 1) for a wet fiber was chosen. The determination of this curve is straightforward and simple, and from the curve various parameters can be selected which can be used to characterize the fibers.

Ten fibers were taken at random from each of the pretreated samples. A load-elongation curve was determined for each of these fibers by means of the Instron Tensile Tester [12].

The fibers were mounted in the following way. A strip containing one row of holes was cut from a 35-mm. photographic film and glued with a solution of the film in acetone to another piece of film as shown in Figure 2.

Gramophone needles and fibers were glued to the

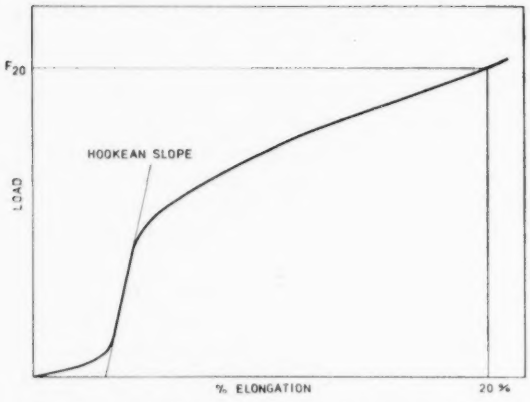

FIG. 1. *Load-elongation curve for a wool fiber.*

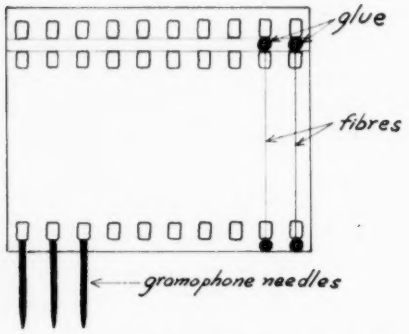

FIG. 2. *Strip of film used for mounting the fibers.*

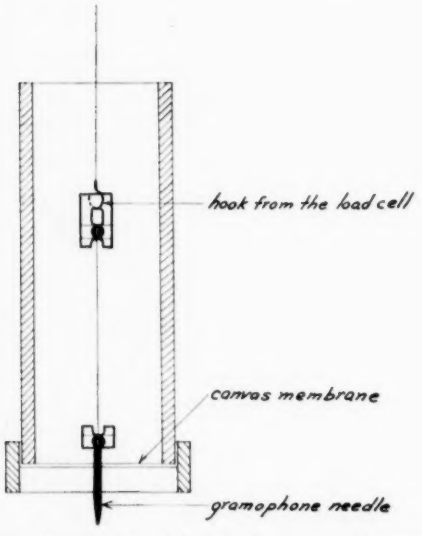

FIG. 3. *Tube used for measurements in water.*

film as shown in Figure 2. While being mounted, the fibers were loaded with 0.5 g. The specimen length was determined by the film width, being 30.9 mm. in this case with a load of 0.5 g. With this technique the mounted fibers were very easily handled. Immediately before measuring a fiber, a strip containing one fiber was cut from the film. The middle part was then cut away close to the points where the fiber was fastened.

The specimen was hung on a hook suspended from the load cell in the Instron Tester, and the needle was attached to a gramophone pickup placed on the crosshead. When the fiber was to be measured in water, the needle was forced through an impregnated canvas membrane in a Perspex tube, as shown in Figure 3, and the tube was filled with water. If necessary, a drop of wax can be melted around the needle to prevent water leakage through the impregnated membrane.

In order to reduce the force, F, for a given point on the load-elongation curve to the specific value, $F/\text{cm.}^2$, it is necessary to know the cross-sectional area of the fiber. The simplest method to measure this area is that proposed by Gonsalves [9], later modified by Dart and Peterson [6]. This method makes use of the relationship between the denier of a fiber and its resonance frequency for transversal vibrations, when the fiber is supported at both ends like a string. The string equation given by Gonsalves is

$$\nu = \frac{a}{l}\sqrt{\frac{P}{\rho A}}\left[1 + \frac{R^2}{l}\sqrt{\frac{E\pi}{P}}\right],$$

where ν = resonance frequency, l = length of fiber at resonance frequency, a = number of waves on length l, P = load on fiber at resonance frequency, ρ = specific gravity of fiber (the value used being 1.30), A = cross-sectional area, R = radius of fiber, and E = Young's modulus.

By suitable choice of l and P the value of the correction term $\frac{R^2}{l}\sqrt{\frac{E\pi}{P}}$ can be made so small that it can be neglected. Thus, the equation reduces to

$$\nu = \frac{a}{l}\sqrt{\frac{P}{\rho A}}.$$

In Gonsalves' method P is kept constant and ν is varied and the resonance is observed by means of a microscope. Dart *et al.* keep ν constant and vary P. The latter principle was used here except that the load at resonance, P, was recorded on the

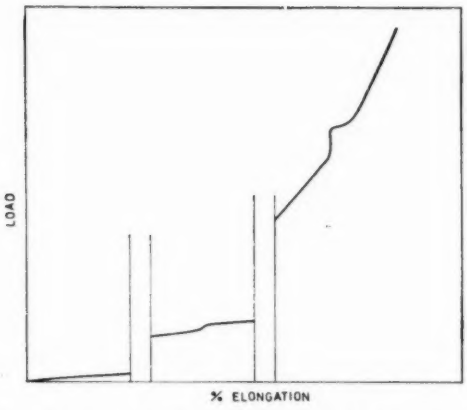

FIG. 4. *Enlargement of the uncrimping region in Figure 1, showing humps due to resonance.*

graph in the Instron Tester. The gramophone pickup in which the fiber was mounted was fed a constant frequency of 1200 c.p.s. The load-elongation curve was determined as usual. Somewhere in the uncrimping region of the curve the tension in the fiber corresponded to the load at resonance and the fiber began to vibrate. At this moment the tension increased suddenly, as shown by a small hump on the curve (see Figure 4). In fact, a series of humps, corresponding to different values of a, can be seen on the curve. The largest hump was formed when a was equal to $\frac{1}{2}$, and the corresponding value of P was selected. After P had been recorded, the vibrator was switched off and the curve completed. By using this method the cross-sectional area and the load-elongation curve can be determined during the same run. A similar method has also been used at Textile Research Institute [27]. From the equation it is seen that A is proportional to P and, therefore, P can be used directly to reduce force, F, to its specific value. Since the length of the fiber is known at 0.5 g., it is easy to determine from the graph the length of the fiber at resonance.

If A is determined from the simplified equation, E can be estimated and used to calculate the value of the correction term. This value was found to be about 0.02. The values of A will, therefore, be slightly low.

Another method used to eliminate the influence of cross-sectional area, thus reducing the variance of different parameters of the load-elongation curve for wet fibers, was suggested by Burte [4]. He

TABLE I. VALUES OF A (μ^2), H (G.), AND F_{20} (G.)

$\sqrt{A}$	$\sqrt{H_{air}}$	$\sqrt{H_{wet}}$	$\sqrt{F_{20}}$	$\sqrt{A}$	$\sqrt{H_{air}}$	$\sqrt{H_{wet}}$	$\sqrt{F_{20}}$
Untreated				*Alcoholic potash, 15 sec.*			
20.1	10.5	7.3	1.30	24.0	11.9	9.4	1.60
19.8	11.8	7.7	1.31	14.9	8.4	5.6	1.00
18.2	11.1	7.3	1.23	14.8	8.0	4.9	.97
18.4	11.2	7.5	1.28	15.7	9.4	5.7	1.01
20.5	12.0	7.9	1.41	21.1	12.4	7.7	1.36
21.4	11.3	7.5	1.46	18.9	10.4	6.7	1.28
15.9	9.2	6.0	1.09	18.5	10.1	6.9	1.22
23.2	11.7	7.9	1.59	25.3	13.3	8.9	1.70
21.5	10.6	6.9	1.45	17.7	9.5	5.7	1.20
17.2	9.9	6.5	1.16	18.5	9.3	6.2	1.27
Ether-extracted				*Alcoholic potash, 4 min.*			
16.7	9.7	6.4	1.11	21.4	11.9	8.2	1.41
18.8	9.6	6.3	1.25	23.0	12.0	7.9	1.56
23.4	11.2	7.5	1.59	18.0	8.8	5.8	1.17
18.7	11.0	7.5	1.30	17.6	10.1	6.6	1.20
20.2	11.3	7.7	1.41	22.4	13.9	9.2	1.53
16.2	10.3	6.2	1.13	18.6	10.8	7.2	1.28
21.4	12.4	7.9	1.41	20.8	12.0	7.9	1.44
19.8	11.7	7.9	1.33	21.0	12.2	8.3	1.44
18.5	11.0	7.3	1.24	20.6	12.1	8.4	1.42
22.2	12.2	8.0	1.55	23.2	12.5	8.6	1.55
Ether- and alcohol-extracted				*Alcoholic potash, 15 min.*			
15.0	8.6	6.0	1.01	18.8	10.3	7.1	1.27
18.2	10.0	6.9	1.23	19.6	10.2	6.5	1.37
20.9	10.3	7.0	1.41	17.0	10.4	7.1	1.16
19.0	10.1	6.4	1.24	16.6	9.2	6.2	1.18
23.8	13.6	9.3	1.59	21.8	10.7	6.9	1.46
15.9	8.9	6.3	1.09	23.4	13.7	8.1	1.60
19.3	11.6	7.6	1.28	16.2	8.4	5.6	1.06
17.0	10.4	7.0	1.12	17.3	10.8	7.1	1.16
16.8	9.2	6.2	1.17	16.1	9.2	5.5	1.04
17.9	10.6	7.3	1.21	23.5	13.6	9.1	1.63

used the ratio $\frac{H_{wet}}{H_{air}}$ to detect slight chemical modifications of the fiber, where H_{wet} is the Hookean slope in water and H_{air} the Hookean slope at 65% R.H. The hypothesis is that these chemical modifications will influence only H_{wet}. It has been shown by Lindberg [19] that the ratio $\frac{H_{wet}}{H_{air}}$ has a lower variance than the ratio $\frac{H_{wet}}{A}$, and also that the ratio $\frac{F_{20}}{A}$ has a lower variance than the ratio $\frac{F_{20}}{H_{air}}$, F_{20} being the force at 20% elongation. Thus, both the cross-sectional area and the Hookean slope were determined while the fibers were conditioned to 65% R.H. The fibers were stretched only 2%–3%, and were afterwards placed in the Perspex tube and relaxed for 5 min. in water as recommended by Burte. After relaxation the load-elongation curve in water was determined. It has been shown that

TABLE II. VALUES OF k_1 AND k_2

Treatments	k_1	k_2
Untreated	.675	.674
Ether-extracted	.689	.687
Ether- and alcohol-extracted	.645	.643
Alcoholic potash, 15 sec.	.783	.676
Alcoholic potash, 4 min.	.707	.682
Alcoholic potash, 15 min.	.586	.721

there is practically no correlation between the Hookean slope and the force at 20% elongation. Therefore, these two parameters have been chosen here to characterize the load-elongation curve [19].

From the curves for the different fibers, values of A, H_{air}, H_{wet}, and F_{20} were determined. It was found that these parameters all had skew frequency curves. If the regression of F_{20} on A is calculated, for instance, a few thick fibers would unduly influence the values of the regression coefficient. To avoid this and to make the frequency curves symmetrical, the square root of the values for the different parameters were used in the statistical calculations. Table I gives the values for $\sqrt{A}$, $\sqrt{H_{air}}$, $\sqrt{H_{wet}}$, and $\sqrt{F_{20}}$.

If $\sqrt{H_{wet}}$ and $\sqrt{F_{20}}$ are plotted against $\sqrt{H_{air}}$ and $\sqrt{A}$, respectively, for the different treatments, straight lines are obtained with the slopes k_1 and k_2, respectively. These values are determined by the method of least squares, and are shown in Table II.

An analysis of covariance of this data (Table III) shows that there is no significant deviation from the mean in either set of regression coefficients. The conclusion is that no measurable change in the mechanical properties occurred in any of the pretreatments. Mercer and Freney [25] measured the breaking strength of fibers untreated and treated by alcoholic potash, and found that there was no change in this property caused by the treatment. It is, therefore, well established that such treat-

TABLE III. ANALYSIS OF COVARIANCE

$\sqrt{H_{wet}} = k_1 \sqrt{H_{air}} + \text{constant}$

Source of variation	Sum of squares (H_{wet})	Sum of squares (H_{air})	Sum of products	Error sum of squares	Degrees of freedom	Mean squares
Within individual treatments						
Untreated	3.42	7.08	4.78	.19	8	
Ether-extracted	4.46	8.14	5.61	.59	8	
Ether- and alcohol-extracted	8.24	18.86	12.17	.39	8	
Alcoholic potash, 15 sec.	19.82	27.36	21.43	3.03	8	
Alcoholic potash, 4 min.	9.19	17.84	12.62	.26	8	
Alcoholic potash, 15 min.	10.70	27.68	16.21	1.21	8	
				5.67	48	.118
Within treatments	55.83	106.96	72.82	6.25	53	
Differences among individual regressions				.58	5	.116

From the mean squares in the last column it is seen that there is no significant difference between individual regressions.

$\sqrt{F_{20}} = k_2 \sqrt{A} + \text{constant}$

Source of variation	Sum of squares (F_{20})	Sum of squares (A)	Sum of products	Error sum of squares	Degrees of freedom	Mean squares
Within individual treatments						
Untreated	.2056	.4376	.2948	.0070	8	
Ether-extracted	.2326	.4747	.3260	.0087	8	
Ether- and alcohol-extracted	.2484	.5920	.3804	.0040	8	
Alcoholic potash, 15 sec.	.5391	1.1660	.7883	.0062	8	
Alcoholic potash, 4 min.	.1760	.3632	.2478	.0069	8	
Alcoholic potash, 15 min.	.4086	.7674	.5535	.0094	8	
				.0422	48	.00088
Within treatments	1.8103	3.8009	2.5908	.0443	53	
Differences among individual regressions				.0021	5	.00042

From the mean squares in the last column the variance ratio is calculated and found to be 2.10, which is just below the 0.95 limit.

ments under regulated conditions do not influence the mechanical properties of the fibers.

Swelling

Transversal swelling of wool fibers in water has been suggested as a method for detecting wool fiber modification [13, 34]. Of the various possible methods of measuring fiber swelling, the centrifuge method was chosen. In this method the excess water is centrifuged from a fiber sample, and the difference between the weight of the sample after centrifuging and its dry weight is taken as an estimate of volume swelling. The method was thoroughly investigated by Preston *et al.* [30], who showed that even after centrifuging for a long time some surface water is still present in the fiber sample. The amount of surface water can be reduced to some extent by adding a surface-active agent to the solution, thereby decreasing its surface tension. The amount of surface water is also, according to Preston *et al.*, dependent upon the surface tension of the fibers. In this case the different samples may have different surface tensions, and thus tending to invalidate the conclusions that may be drawn from the experiments. The effect, however, is thought to be negligible.

About 1 g. of fibers was placed in a buffer solution at pH 6 containing 0.1% of a wetting agent (Berol VMA-309). It was kept there for 1 hr., removed, and centrifuged for 15 min. in a centrifuge producing 1,000*g*. The samples were weighed immediately after centrifuging, dried at 105°C for 1 hr., and reweighed. The volume swelling is given in Table IV as percent of water based on dry weight.

The results from both stress-stain data and swelling data show that there was no change in the properties of the fibers during the pretreatments used. From the results obtained here it follows that the changes in the physicochemical properties of the wool samples, which are discussed below, must be a result of surface modification.

Allwörden Reaction

If wool fibers are immersed in chlorine or bromine water, small bubbles will appear along the surface of the fibers after a short time [3]. It is suggested that the epicuticle acts as a semipermeable membrane [17] which is kept expanded by the osmotic pressure sustained by the degraded protein [28]. It has long been argued that if the fibers have been modified by an alkali treatment, the formation of bubbles will be inhibited. Recently it has been shown by Meeuse [24] that the bubbles always do appear, but it takes much longer for them to form after an alkali treatment. An acid treatment, on the other hand, shortens the time of formation. In all cases the epicuticle must, of course, be intact. If it is impaired or removed, no Allwörden bubbles will be formed.

TABLE IV. SWELLING OF DIFFERENTLY TREATED FIBERS

Treatment	Percentage swelling*
Untreated	34.3
Ether-extracted	33.3
Ether- and alcohol-extracted	33.2
Alcoholic potash, 15 sec.	33.4
Alcoholic potash, 4 min.	33.9
Alcoholic potash, 15 min.	33.7

* Each value is the mean of four determinations.
The standard error (0.95 limit) for the difference between two treatment means was found to be 1.2.

Fibers from all the pretreated samples were mounted on microscope slides, and bromine water was drawn under the cover glasses by means of blotting paper. It was found that all samples showed the same reaction time (approximately 1 min.). Treatment with alcoholic potash did not change the reaction time, contrary to expectation. It was expected that this treatment should modify the epicuticle to such an extent that the protein molecules would be able to diffuse through it, preventing the formation of osmotic pressure under the epicuticle. The reason for this presumption is that after treatment with alcoholic potash, acids and dyes show a marked increase in their rate of penetration into the fibers [7, 14, 18].

This difference in the behavior of dye molecules from that of the protein molecules can probably be attributed to their difference in size. Another explanation is that the basic molecular structure of the epicuticle may not be influenced by the alkali treatment, an assumption that is supported by the fact that the epicuticle is quite inert and is dissolved by alkali only at relatively high temperatures or by very prolonged treatment. The action of alkali should instead be that of transforming the epicuticle from a nonpolar to a polar substance, thus increasing the reactivity with hydrogen ions or other ions. This is merely a suggestion to account for the fact that the epicuticle is so sensitive to alkali, as judged from the increased rate of acid and dye penetration, and yet is so difficult to dissolve even in strong alkali.

It is evident that the explanation for the increased

reaction time after treatments with water solutions of alkali must be found somewhere else than in the epicuticle. The samples were therefore given an additional treatment in a buffer solution of pH 11. The reaction time then increased to about 4 min. for samples which were both treated with alcoholic potash and untreated.

This aqueous alkali treatment affects the interior of the fiber as well as the exterior, thus accounting for the increased reaction time after treatment. Neish and Speakman [29] have shown that the effect of chlorination on the rate of felting is greatly reduced after a pretreatment of alkali, and they attributed this to the fact that some cystine linkages are transformed to lanthionine linkages, the latter being more resistant to chlorine. This was confirmed by Lindberg and Gralén [20], who measured the actual mechanical resistance of the scales and also found that a pretreatment with alkali made the scale substance more resistant to chlorine.

It is therefore suggested that the reaction time is dependent upon the rate of reaction between chlorine or bromine and the protein substance in the scales. The products of high-molecular protein degradation, responsible for the osmotic pressure under the epicuticle, are formed at a lower rate after alkali pretreatment and thus it takes longer for the bubbles to appear.

This suggestion is further confirmed by the results of an acid treatment. It has been found in this laboratory that boiling the wool for some time in an acid solution (pH 2) increases the rate of penetration of dyes due to the action of acids on the permeability of the epicuticle. The reaction time for the Allwörden bubbles to appear, however, is decreased [24]. This gives further indications that the reaction time is independent of the condition of the epicuticle. It has also been shown by Alexander *et al.* [1] from direct measurements of the reaction rate between chlorine and keratin that an acid pretreatment increases the reaction rate.

It can be concluded that Allwörden's reaction will indicate the absence or disruption of the epicuticle, and will also indicate whether the bulk structure, or, better, the scale substance, has been modified. It should be noted that an increase of the reaction time has long been considered an indication of the extent of wool fiber damage by alkali, while, according to the hypothesis put forth here, the fibers are more resistant to halogens. If this hypothesis is accepted, the present results further confirm the conclusion drawn above—that the effect of an alcoholic potash treatment is confined to a thin surface layer.

Staining Reactions

Numerous dyes have been suggested as staining agents to detect chemical modifications of wool fibers [24]. Of those suggested, three were chosen—Methylene Blue, Methyl Orange, and diazobenzene sulfonic acid or Pauly's reagent. The pretreated samples were stained with these reagents using the following procedure.

Fibers were cut in small pieces in a mill composed of two knives and a rotating cutter. A small amount of the cut fibers was placed in 10 ml. of a solution of the reagent for 5 min. at room temperature. The solution was filtered off, and the fibers were washed, dried, and mounted in glycerol on microscope slides. One-hundred fibers were counted and divided into three classes according to their depth of color. The Methylene Blue solution contained 0.1 g./l., the Methyl Orange solution contained 1 g./l., and the Pauly's reagent was prepared according to Rimington [31]. The results obtained are shown in Table V.

Differences among different samples may be tested by means of χ^2-analysis, a method which was suggested by Robinet [32]. It is generally agreed that Methylene Blue stains fibers that have been oxidized or chlorinated much more deeply than normal fibers. It is seen from Table V that the samples treated with alcoholic potash are stained to a smaller degree than the extracted samples. This fact was

TABLE V. NUMBER OF FIBERS STAINED BY VARIOUS AGENTS

	Methylene Blue			Methyl Orange			Pauly's reagent		
Treatment	1*	2*	3*	1	2	3	1	2	3
Untreated	48	41	11	100	—	—			
Ether-extracted	55	37	8	99	1	—			
Ether- and alcohol-extracted	47	42	11	100	—	—	54	44	2
Alcoholic potash, 15 sec.	97	2	1	55	43	2			
Alcoholic potash, 4 min.	90	9	1	26	64	10			
Alcoholic potash, 15 min.	97	2	1	34	64	2	19	61	20
Buffer solutions, pH 6	93	5	2	89	11	—			

* 1 = unstained; 2 = slightly stained; 3 = heavily stained.

also observed by Freney and Lipson [7]. An untreated sample, however, steeped in a buffer solution at pH 6 at 50°C for 30 min. produces the same results as the alcoholic potash treatment. This result is probably associated with the fact that the untreated and extracted samples had not been brought into contact with water before staining. The water treatment may remove some chemical agents responsible for the staining of these samples.

The degree of staining with Methyl Orange and Pauly's reagent is very much increased after treatment with alcoholic potash. With Pauly's reagent the same result is obtained by Freney and Lipson [7] and Glynn [8].

These results, combined with the fact that the bulk part of the fiber is not modified by alcoholic potash treatments, suggest that there are two types of staining agents: (*a*) agents which selectively stain different types of keratin or chemically modified keratin; (*b*) agents which stain what is considered to be normal keratin (all dyes for wool belong to this group).

A necessary condition for using a staining reagent as a test for any modification of the keratin in the bulk part of the fiber is that the agent has free access to this part. If this condition is not met, then the results of this test are not valid, and cases where such availability varies cannot be compared. For comparison purposes the interior of the fiber must be exposed to the reagent. This can be done in the following way. Untreated fibers are mounted in a Hardy microtome [33], the protruding ends are cut off, and the reagent is placed on the fiber ends in the form of a small droplet. Then a thin cross section is taken and viewed under the microscope. With this technique it was found that Methylene Blue, as before, stains only very few fibers, and therefore is of type (*a*). Methyl Orange and Pauly's reagent, on the other hand, stain all fibers equally, and consequently are of type (*b*).

It is obvious that if an unstained fiber is obtained when the latter two reagents are used in the conventional manner (using long pieces of fibers), then the interior of that fiber was not available for combination with the reagent. Somewhere in the surface layer there must be a barrier which prevents the staining reagent from entering the fiber past its surface.

Several authors have observed that the cuticle greatly influences the ability of the fiber to be stained with various staining reagents [11, 31]. Carter and Consden [5] have found, for instance, that a mechanically descaled fiber stains much more deeply with Kiton Red G than does a normal fiber. Millson and Turl [26] have also shown that most dyes and heavy metal salts, under appropriate conditions, produce the same patchy staining that is usually obtained with Pauly's reagent, and that the appearance of these stains depends upon the condition of the cuticle.

The present experiments indicate that the part of the cuticle which was responsible for the degree of staining in the above cases was the epicuticle, since any modification by alcoholic potash was confined to this layer.

This means that if the epicuticle is disrupted or punctured, the staining reagent will enter the fiber through the holes formed, resulting in a deeply dyed patch [21, 26]. The epicuticle, being a surface layer, is very susceptible to mechanical damage of this kind during processing and when in use, and, therefore, trouble may be encountered in the dyeing or redyeing of wool textile material. It is understood that any dye with an affinity for keratin, under appropriate conditions, may by used as a staining agent of type (*b*), and the author has used both acid dyes and premetallized dyes with success to assess the degree of damage to the epicuticle in various wool samples. The influence of the epicuticle on dyeing will be discussed in later papers in this series which deal with the rate of sorption of dyes.

Conclusions

It is obvious that there is no correlation between the results of fiber modifications obtained from reactions with staining reagents of type (*b*) and the results obtained from load-elongation curves, swelling, and Allwörden's reaction. Fundamentally different properties are measured in the different cases. If such a correlation is obtained, it must be looked upon with suspicion, since some chemical reagent—*e.g.*, alkali—may have influenced the bulk part of the fiber as well as the epicuticle to such an extent as to distort some result, such as the load-elongation curve. There can never be a general correlation between different methods for estimating wool fiber modification as long as the results of these methods are dependent upon the condition of different morphological components and physicochemical properties that can be changed independently by various treatments.

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Application of High Compression Stresses to Textile Fibers

Part I*

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Contribution of the Institute of Textile Technology, Charlottesville, Virginia

Introduction

The Problem of Evaluating the Quality of Cottons

Great progress has been made during recent years in developing laboratory tests of cotton fiber properties. These tests enable us to predict much of the behavior of the fibers during processing and use. However, it is well recognized that the tests are not always adequate for the job. This is particularly true when we try to predict the spinnability of cotton.

New crop cottons often give trouble from excessive ends down or uneven or weak yarns, even though laboratory tests of the length, strength, firmness, and maturity of the fibers do not show any reason to expect trouble. Sometimes the troubles disappear after the cottons have aged a few months, even though laboratory tests of the fibers again show no change during this period. In other cases, a cotton which is raw stock dyed with one dye may spin well, while it may cause trouble if dyed with a different dye. We cannot attribute such differences to any change in strength, fineness, or maturity of the fibers. Some other property which was not measured must have been changed.

The cotton classer may sense these other fiber properties, and include them in his subjective judgment of the "character" of the cotton. When cottons are raw stock dyed with different types of dyes, certain differences in the "harshness" or slip or "scroop" of the fibers can easily be recognized even by a novice. In other cases the differences, if they exist, are much more subtle. But if the fibers behave differently during drafting, there must be some physical differences between them, and these differences should be measurable in the laboratory. If we only knew what to look for, means could be developed to make these measurements.

An analysis of the spinning process suggests that one of the important factors in drafting may be the friction of the fibers against each other and against the drafting rolls. Attempts have been made at the Shirley Institute, the U. S. Dept. of Agriculture, and elsewhere, to measure the interfriction or "drag" of fibers, but to date this work has not resulted in any published tests which greatly increase the reliability of laboratory predictions of spinnability. One reason for this lack of success might be the change of the coefficient of friction of fibers against fibers (and against the drafting rolls) with the pressure forcing the materials together. Fibers might also differ in their resistance to cutting when pressed across other fibers.

These and other reasons suggested the need of exploring the behavior of fibers when they are compressed in a random mass at high pressures. While the work was stimulated by a desire to find a test that would predict the spinnability of cotton, it led to an almost unexplored field of fiber behavior which was worth investigating even though the results might have no relation to spinnability. This paper reports the results of preliminary scouting tests of this type on cottons and a few other fibers. The behavior of various synthetic fibers under high compression stresses is reported in Part II (p. 84).

Compression Stresses Applied to Cottons in the Gin, Mill, and Service

What are the pressures to which cotton fibers are subjected in normal baling and spinning operations? A detailed analysis of the mechanical operations applied to the fibers in their passage through the gins, compresses, cards, and spinning frames shows that these pressures may be astoundingly high—far

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higher than have been applied in any reported laboratory fiber compression tests.

In the gins, the saw blades hook on to kinked single fibers or groups of fibers, and yank them from the seeds at high speeds. The compression and shear stresses applied to the fibers by this process may be so high that if the fibers are wet and plastic they will be deformed, or even cut in two. Even if the fibers are dry, one fiber may get looped around another, and then be pulled until one of them breaks.

If the tensile strength of each fiber making the loop is, say, 100,000 lbs./sq. in. of cross-sectional area, only a few grams force would be required to break it in a straight tensile pull. However, if the fibers are roughly square in cross section, and the strength is not decreased by bending the fibers, then the compressive stress at the surface where the two looped fibers are in contact would be in the neighborhood of 200,000 p.s.i. Even if the bending reduced the strength to only about one-quarter of its maximum value, compressive stresses of about 50,000 p.s.i. could be encountered.

Similar effects of tearing looped fibers are even more frequent at the licker-in and the doffer rolls of the card.

In baling the ginned cotton, very large compressive forces are applied to the ends or sides of the bales, but these forces are applied over large areas, so that the unit pressures are only a few hundred pounds per square inch.

The drafting process may involve putting fibers between a fluted metal roll and a cork- or rubber-covered roll, these rolls being pressed together with a force of about 10 lbs./in. of roll length. This gives calculated average pressures between the rolls of about 150 p.s.i., and pressures at the edges of the flutes may be 10 to 100 or more times the average value.

High compressive stresses may occur between fibers not only in processing, but also in service. The compressive stresses produced by the outer strands of a rope may crush the central strand to bits. It is known that the tensile strength of a tire cord cannot always be calculated from the strength of the yarns that go into it. This might be related to differences in the resistance of the fibers to compression stresses.

Since textile fibers may be subject to very high compressive stresses in processing and in service, a knowledge of the behavior of cottons under such stresses might be of considerable value.

Prior Work on Laboratory Compression Tests of Cotton

A number of workers—*e.g.*, Rees [5] and Mutschler [4]—have studied the recovery of fibers from compressive stresses, but, like most workers in this field, they used pressures of the order of 1 p.s.i.

The U.S.D.A. laboratories [3, 7, 8] and the Indian cotton laboratories [1] have studied the effects on spinning quality of baling cotton to densities of about 20, 30, and 40 lbs./cu. ft. There was some evidence that compressing to densities above 40 lbs./cu. ft. tended to injure the cotton. These densities require pressures of about 1,000 p.s.i. [6].

In a report by the Textile Research Institute [2] Campbell called attention to the possible damage to cotton from compression to high densities, and suggested that laboratory studies be made of the effects of higher pressure on cotton, but no such studies have been found in the literature.

Experimental

Hand Compression Tests

Two samples of raw stock dyed cotton prepared from the same lot of fibers by the Grantville Mills were used for the initial tests to see if there was any relation between the recovery of fibers from compressive stresses and their spinnability. These samples had the same fiber shapes since they were prepared from the same lot of cotton. One sample was dyed blue with a drastic dyeing procedure, and gave a great deal of trouble on subsequent spinning. This sample felt dry and harsh to the hand. The other sample was dyed yellow by a much milder dyeing procedure, and felt soft and flexible. It gave little trouble in spinning. When these samples were compressed and rubbed in the hand, the blue sample showed a harsh "stick-slip" type of friction, and the fibers tended to mat together in lumps and had poor recovery. The yellow sample was much softer and smoother and compressed more readily, but it showed almost no tendency to mat, and remained more or less fluffy.

These results suggested that the blue fibers which have poor spinnability may have a tendency to stick together when slid over each other under pressure and that this sticking and spinnability might be related. Methods of measuring the recovery of fibers from various types of compressive stresses were then developed.

Quantitative High Compression Tests

The above raw stock dyed samples and three others of widely different surface properties were used to study several compression tests at a wide range of loads.

The additional samples included a commercial cotton of $1\frac{1}{16}$-in. staple and two samples of cotton batting. One of these was a heavily scoured absorbent cotton that had friction properties like those of the blue dyed cotton, but more so. It felt harsher, had more "scroop" or "stick-slip" type of friction, and tended to mat even more than the blue cotton when rubbed in the hand. The other sample of cotton batting was nonabsorbent, and so presumably was unscoured and still coated with the natural oils and waxes. It felt smooth and silky, with none of the "scroop" of the absorbent cotton. While no one would try to spin these last two cottons (which probably were made from card strip waste), they were selected because they might show, in an exaggerated degree, the effects of factors which are present, but not recognized, in other cottons where the effects are smaller and often masked by other factors.

The properties of these cottons are shown in series *I* of Table I. The table also shows the properties of a second series of cottons, obtained from the U.S.D.A., which were used in later tests.

The cottons of series *I* were first compressed under light loads ($\sim$ 1 p.s.i.) with and without vibration. Samples 1 and 3, which felt the harshest and stiffest, showed the lowest compressions and highest recoveries. This was not in accord with the known relative spinning behavior of samples 1 and 2, or their recovery in hand compression tests, so other compression tests were explored.

When the pressures were increased to the range 100 to 20,000 p.s.i., the samples behaved very differently. The first test at these pressures was made by taking $\frac{1}{2}$-g. samples of each cotton, folding them into about 1-in. squares, and pressing them for 1 min. between 1-in. square platens in a Carver laboratory press. After the pressure was applied for the desired time the samples were examined.

After a nominal pressure of 1,500 p.s.i. was used, samples 2, 4, and 5 recovered much of their original shape with no apparent damage to the fibers. Samples 1 and 3, however, recovered only slightly, and had glazed areas on their surface. Here the fibers appeared fused together, or else so tightly mashed that they gave a glossy surface. The glazed areas of the sample did not expand after the pressure was removed, but remained as smooth, depressed areas when the surrounding fibers tended to return to their original shape.

After pressures of 20,000 p.s.i., the samples 2, 4, and 5 had some glazed areas but samples 1 and 3 were glazed over the whole surface and showed almost no recovery. When the samples were flexed, the fibers appeared to be pulverized and fell out as a powder. Microscopic examination of the samples

TABLE I. FIBER PROPERTIES OF COTTONS

Sample type no.	Fibrograph U.H.M. (in.)	Micronaire fineness	Pressley fiber strength (lbs./mg.)	Skein strength, 22's (lbs.)	Hand rubbing test
		Series I			
1. Blue dyed raw stock	0.99	4.4	6.10*	—	Harsh, some scroop
2. Yellow dyed raw stock	1.00	4.4	5.57*	—	Softer and smoother than sample 1
3. Absorbent, J & J	0.69	4.8	5.63*	—	Very harsh, high scroop
4. Nonabsorbent, J & J	0.80	4.3	5.91*	—	Softer and silkier than sample 2
5. Commercial, $1\frac{1}{16}$ in.	1.10	3.6	5.76*	—	Normal
		Series II			
1. AHA 6-1-4	1.10	4.9	8.59	159	—
2. Rowden	0.95	5.3	8.33	108	—
3. Deltapine 15	1.06	4.8	7.48	118	—
4. Sealand	1.29	3.1	7.33	131	—
5. Acala 1517W	1.09	4.1	8.53	140	—
6. Station C, Tifton, Ga.	0.99	3.9	6.51	93	—

* Measured with Pressley Jaws on Scott IP-4 Machine.

by Mr. T. L. W. Bailey, Jr., showed that the fibers in the glazed areas were mashed, crushed, and cut into tiny pieces a fraction of a millimeter long.

Further tests showed that the yellow dyed cotton began to get glazed areas at pressures of about 7,500 p.s.i., compared with pressures of 1,500 p.s.i. for the blue cotton. This difference of about fivefold in pressure to cause glazing was far greater than the relative difference in any other property of these fibers which was measured. It suggested that a more quantitative study of the effects of high pressures on cottons should be made.

Quantitative Recovery Tests

Comparison of cottons.—The compression test was refined by placing 1 g. of the fibers in a cylinder 1.132 in. in diameter (1.064 sq. in. area) and compressing them with a tightly fitting piston (1.127 in. diameter). Both the piston and cylinder are preferably made of stainless steel to minimize corrosion and distortion. Pressure was applied through a Carver laboratory press. After the fibers were compressed the desired time (usually 30 sec.), they were removed from the cylinder, and the thickness of the compressed plug was measured at various times. The thickness

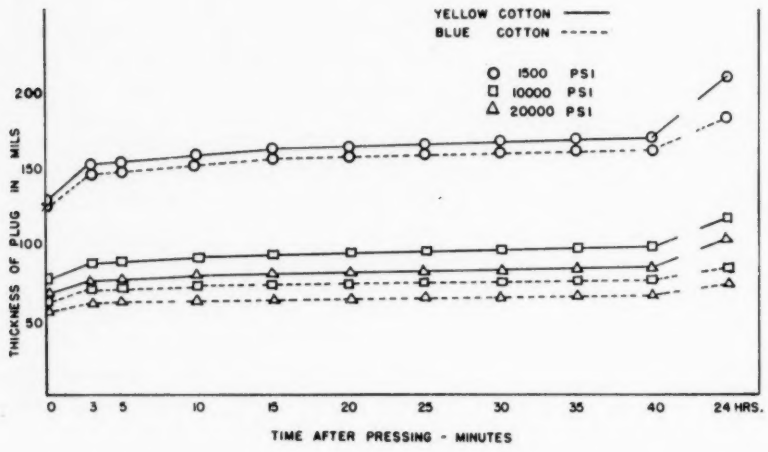

FIG. 1. *Recovery of yellow and blue dyed cottons.*

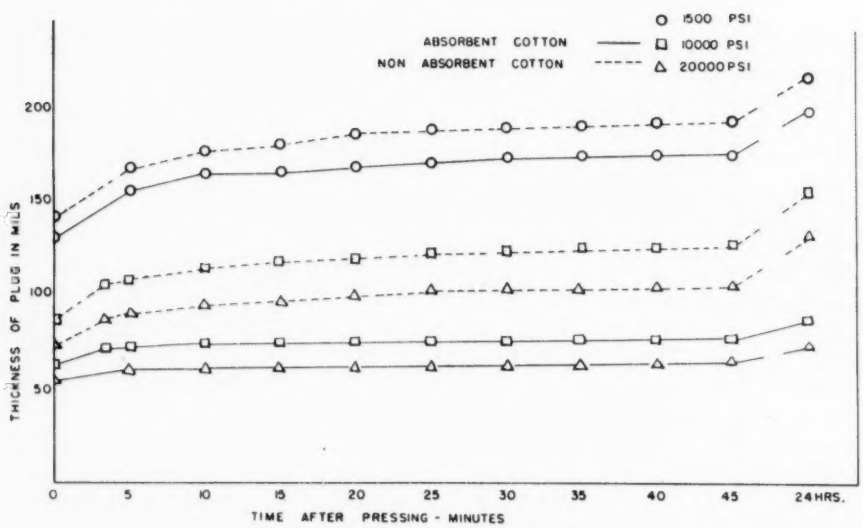

FIG. 2. *Recovery of absorbent and nonabsorbent cottons.*

measurements were made while the sample was under a pressure of 2 p.s.i.

When the 1-g. samples were used, the fibers could be distributed more uniformly across the area of the piston, so that there was less chance of building up local high pressure areas. Consequently, considerably higher gage pressures had to be used to get glazing of the samples than were required in the first test. Since the "glazing" is hard to measure quantitatively, only the recovered heights were measured.

The recovery of the blue and yellow cottons at various times after a 30-sec. compression are shown in Figure 1. At the lowest pressure used in this test (1,500 p.s.i.) the recoveries of the two cottons were about the same, although the blue cotton has better recovery at much lower loads (1 p.s.i.). At the higher pressures the yellow cotton has better recovery than the blue.

The relative recovery of these two cottons actually differs much more than does the ratio of the recovered heights shown on the graphs. When the samples are compressed by the piston, the fibers are bent and kinked so they will fit into a smaller volume. However, they cannot be deformed to occupy a volume much smaller than the total volume of the cellulose in the fibers. This gives a minimum height for a 1-g. sample of about 0.048 in., so that recoveries should be figured from this sample height.

TABLE II. RELATIVE RECOVERIES OF COTTONS AFTER COMPRESSION

	1,500 p.s.i.	10,000 p.s.i.	20,000 p.s.i.
A. Blue and yellow cottons			
Recovered height (in.)			
Yellow	0.167	0.096	0.083
Blue	0.160	0.076	0.065
Ratio yellow/blue	1.04	1.26	1.28
Recovered height—0.048 in.			
Yellow	0.119	0.048	0.035
Blue	0.112	0.028	0.017
Ratio yellow/blue	1.07	1.72	2.08
B. Absorbent and nonabsorbent cotton			
Recovered height (in.)			
Nonabsorbent	0.188	0.123	0.102
Absorbent	0.172	0.076	0.063
Ratio nonabsorbent/absorbent	1.09	1.62	1.63
Recovered height—0.048 in.			
Nonabsorbent	0.140	0.075	0.054
Absorbent	0.124	0.028	0.015
Ratio nonabsorbent/absorbent	1.13	2.68	3.62
C. Extracted and nonextracted cotton			
Recovered height (in.)			
Original	0.185	0.116	0.095
Extracted	0.189	0.087	0.077
Ratio original/extracted	0.97	1.33	1.23
Recovered height—0.048 in.			
Original	0.136	0.068	0.047
Extracted	0.141	0.041	0.028
Ratio original/extracted	0.97	1.66	1.66

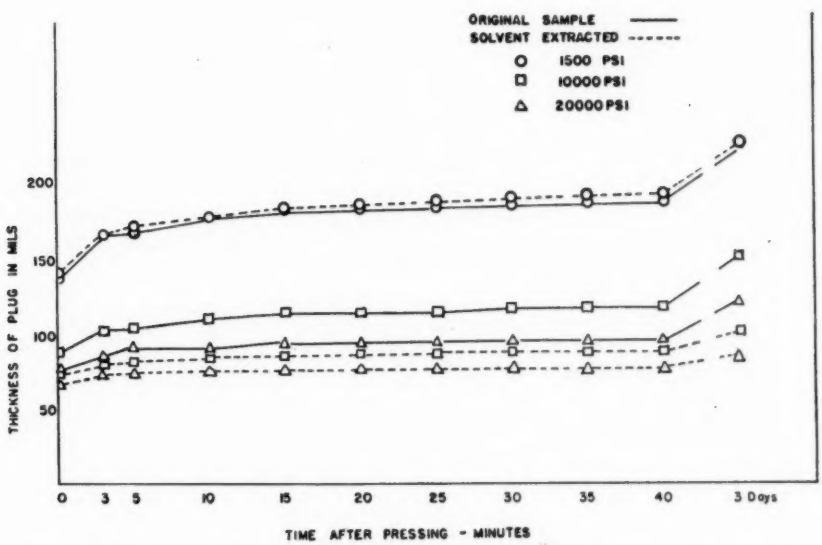

FIG. 3. *Recovery of original and solvent-extracted samples of 1⅛-in. Wilds cotton.*

Table II, section *A*, shows the recovered heights of the blue and yellow cottons at 30 min., and the ratios of these heights. These ratios of recovered heights of the yellow to blue cottons vary from 1.04 at 1,500 p.s.i. compression to 1.28 for a compression load of 20,000 p.s.i. When the recoveries are calculated from a base height of 0.048 in., the ratios of recoveries go from 1.07 to 2.08. Thus, the higher the pressures, the greater the difference between these cottons, and these differences are in line with their general spinning performance in the mill.

Similar calculations for the absorbent and nonabsorbent cottons are shown in Figure 2 and section *B* of Table II. Here the ratios of the recovered heights (from a minimum of 0.048 in.) vary from 1.13 for 1,500 p.s.i. to 3.62 for 20,000 p.s.i. This is an even greater change than that obtained with the raw stock dyed samples, and appears consistent with the "feel" of these samples. It is also what one would expect if he tried to spin such heavily scoured fibers.

The scouring process and the more drastic dyeing process may affect the fiber recovery by changing either (or both) of two factors: (*1*) the waxes on the surface that affect the friction properties; (*2*) the inherent structure, stiffness, or elasticity of the fibers.

An attempt was made to separate the effects of these factors by comparing fibers of 1¼-in. Wilds cotton before and after extraction with hot CCl_4. This should tend to remove the surface waxes without having much effect on the bulk properties of the fibers, except that it might remove moisture or "internal lubricants." Recovery data from compression tests on these fibers are shown in Figure 3 and part *C* of Table II. Here the recoveries of the two samples are essentially identical when 1,500 p.s.i. pressure is used, but the unextracted samples recover more from pressures of 10,000 or 20,000 p.s.i.

The ratios of recoveries from the 0.048-in. base line range from 0.97 at 1,500 p.s.i. to about 1.66 at the higher pressures. These figures are lower than the corresponding ratios in parts *A* and *B* of the table. This suggests that, while the solvent extraction harms the fibers, it is less harmful than the treatments given the absorbent and the blue dyed samples.

The cottons shown in series *II* of Table I were tested at a range of pressures, and the recovered heights of the samples at 30 min. are shown in Table III. There appear to be significant differences between the samples, and the order of recovered heights changes with the pressure. There are too few samples in this series to determine whether recovered heights might be combined with length, strength, and fineness tests to give better predictions of skein strength. Such comparisons should be made on a wider range of cotton.

TABLE III. RECOVERY OF COTTONS FROM U.S.D.A.

Cotton	Recovered heights (in.) after pressures of: 1,500 p.s.i.	10,000 p.s.i.	20,000 p.s.i.
AHA 6-1-4	0.223	0.115	0.099
Rowden	0.200	0.115	0.098
Deltapine 15	0.202	0.122	0.094
Sealand	0.202	0.114	0.091
Acala 1517	0.222	0.127	0.093
Station C, Tifton, Ga.	0.178	0.109	0.087

TABLE IV. RECOVERY OF DIFFERENT KINDS OF FIBERS

Fiber	Recovered heights (in.) after pressures of: 1,500 p.s.i.	10,000 p.s.i.	20,000 p.s.i.
Bright viscose staple, 1.5 den.	*	0.089	0.086
Wilds cotton, 1¼-in. staple	0.185	0.116	0.095
Nylon filament, drawn staple	0.175	0.190	0.160
Nylon staple, 1.5 den.	0.275	0.258	0.242
Nylon staple, 6.0 den.	*	0.220	0.223
Scoured wool	0.269†	0.215	0.205
Wool tops	0.262†	0.232	0.205

* Sample would not form a coherent plug.
† Plug distorted; the value given is a minimum figure for recovery.

Comparison of different types of fibers.—The recoveries of a number of natural and synthetic fibers 30 min. after compression to various loads are shown in Table IV. It is apparent that there are enormous differences between the recoveries of the fibers in this test, with wool and nylon being by far the best, cotton intermediate, and rayon the worst. It is interesting to note that nylon which has been converted from filament to staple by a cold-drawing process has far lower recovery than regular nylon.

Effects of fiber treatment on recovery.—Samples of 1¼-in. Wilds cotton were treated by soaking the fibers in various materials at room temperature, conditioning, and compressing to pressures of 30,000 and 40,000 p.s.i. The recovered heights were then measured after 30 min. These pressures were obtained with a cylinder and piston of 0.50 sq. in. area, and a 0.50-g. sample was used. The results of a few scouting or exploratory tests are shown in Table V.

While the differences between some of these single tests are not large enough to eliminate all chance

TABLE V. EFFECT OF TREATMENTS OF COTTON

Treatment	Recovered heights (in.) after pressures of: 30,000 p.s.i.	40,000 p.s.i.
None	0.076	0.074
CCl_4-extracted	0.080	0.073
5% Mineral oil in CCl_4	0.071	0.071
H_2O + Aerosol OT	0.069	0.066
H_2O + AH Covel cationic softener	0.060	0.059

that they are due to experimental error, the larger differences probably are real. It was surprising to find that the mineral oil treatment appeared to decrease the recovery of the fibers. The oil probably had little effect on the bulk elastic or plastic properties of the fibers, so the result must have been due to the changed surface friction. It is possible that the lubricating effect of the oil may have allowed the fibers to slip and readjust themselves to occupy the smallest possible volume under the compressive force. Then, when the pressure was released, the tackiness of the oil may have tended to make the fibers stick together and retain more of their kinky compressed shape, thus reducing the recovery.

The effects of the Aerosol wetting agent and the cationic softener may well have been due to changes in the bulk properties of these fibers to increase their plastic flow.

Effects of compression on tensile properties of fibers.—Initial tests on small samples showed that when the glazed areas of compressed samples were flexed, the crushed fibers fell out as a powder. When larger samples were compressed in the 1-in. area cylinder, there was much less glazing of the surface and powdering of the fibers. A few tests showed that if the end of the piston in contact with the fibers were made even slightly wedge or cone shaped, the fibers would be cut. However, it was hard to find differences between cottons by this test.

Another attempt to explore the effect of high compression forces on the subsequent tensile properties of the fibers involved compressing cottons to 20,000 p.s.i. with the flat die, and then combing and making a Suter array of the fibers from the compressed samples. This was done with 1¼-in. Wilds cotton, and with similar cotton that had been extracted with CCl_4. It was found that the weighted mean length of the fibers from the regular Wilds cotton after compression was $\frac{15}{16}$ in., while the mean length of the extracted fibers was $\frac{7}{16}$ in. Evidently, the CCl_4 extraction made the fibers so brittle that the compression, or the subsequent combing, caused severe breakage of the fibers.

One test showed that fibers which had a normal length after removal from a plug that had been compressed to 20,000 p.s.i. also had normal tensile strength. To avoid having to comb out the highly kinked fibers after compression to measure their strength, another test was explored. Groups of untreated fibers were combed and tied into bundles such as are used in the Pressley test. A number of these bundles were then piled up with successive bundles at 90° to form a cross. The bundles were held in a suitable jig, and pressures from 10,000 to 50,000 p.s.i. were applied by a plunger (usually ⅛- to ¼-in. square) at the center of the cross. The bundles were then broken in the usual Pressley test. Results were quite erratic, as some bundles in a pile might be cut through at a nominal pressure of 20,000 p.s.i., while in other tests pressures of 40,000 to 50,000 p.s.i. would cut through only 4 or 5 of a group of 6 bundles. If the bundles were not cut through, the strength of the fibers was affected compartively little by the initial compression. With considerable refinements, such a test might be made to yield a measure of the true compression strength of fibers.

Conclusions

These exploratory tests show that cotton fibers may differ greatly in their response to high compression stresses. There are suggestions that these differences may be related to processing or service properties of the fibers, but further work will have to be done to confirm these relations.

The recoveries of fibers from bulk compression tests appear to depend, in part, upon the bulk properties of the fibers, such as the elasticity and plastic flow, and the strength and ultimate elongation for tensile, compression, and shear stresses. They may also depend upon the surface properties of the fibers, such as coefficient of friction and adhesion or tackiness, or tendency of the fibers to weld together when sliding past one another under pressure.

As the compression pressures are increased from a few pounds per square inch (as commonly used in laboratory tests) to many tons per square inch (as may be applied to the fibers in processing or in some kinds of service), the relative recoveries of different fibers may change and even reverse. This shows that

the behavior under high loads may be controlled by different factors from those at low loads.

Natural and synthetic fibers vary over a wide range in their recoveries from high compression stresses. Some fibers (wool and nylon) show high recoveries from compression to 30–40,000 p.s.i., while others, such as drastically scoured cottons, may be crushed to a powder by much lower pressures.

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Application of High Compression Stresses to Textile Fibers

Part II*

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In Part I of this series (p. 77) a test for subjecting textile fibers to high compressions was described, the application of this test mainly to cotton was discussed, and theories of fiber physics involved in the deformations and recoveries were given. The discussion is here extended to a large number of textile fiber types and a number of physical and chemical treatments of these fibers. Emphasis is given to mechanical and physical explanations of these phenomena and to the usefulness of the results.

Experimental

The test was performed as follows: 0.3 g. of staple fiber was loaded into a cylinder (see Figure 1) of approximately $\frac{1}{2}$ in. diameter bore; a piston was inserted into the top of the cylinder, and the assembly was compressed in a hydraulic press to a total load of either 2,000 lbs. or 20,000 lbs. (the resulting pressure on the fiber was 10,000 p.s.i. or 100,000 p.s.i.); the pressure was maintained for 1 min. and then promptly released. The resulting pellet was removed from the cylinder and allowed to recover. During recovery most pellets retained their cylindrical shape. Their heights were measured after 15 min., 2 hrs., 24 hrs., and 72 hrs. recovery. Pellets whose recovered

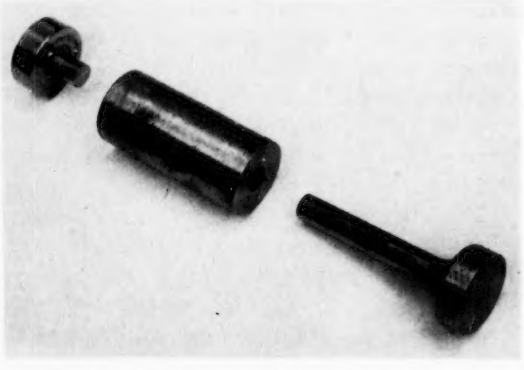


FIG. 1. *Assembly for high compression test.*

* Presented at a meeting of The Fiber Society at Clemson College, Clemson, S. C., Apr. 16, 1952.

TABLE I. RANKING OF VARIOUS FIBERS IN HIGH COMPRESSION STAPLE TEST (PRESSURE OF 100,000 P.S.I.)

Fiber	Initial height (in.)	15-Min. recovery (in.)	(%)	2-Hr. recovery (in.)	(%)	24-Hr. recovery (in.)	(%)
Rubber	0.25	0.25	100	→			
Elastic nylon (0–5)	.30	.30	100	→			
Saran	.80	.80	100	→			
Nylon	1.00	.90	90	0.92	92	0.16	96
Wool	1.00	.31	31	.42	42	.52	52
Casein	.50	.12	24	.12	24	.13	26
Vicara protein fiber	.72	.16	22	.18	25	.20	28
Orlon acrylic fiber	1.20	.20	17	.20	17	.22	18
Acrilan acrylic fiber	1.25	.19	15	.21	17	.23	18
Dacron polyester fiber	1.10	.16	14	.17	16	.20	18
Dynel	1.20	.14	12	.14	12	.15	12
Acetate	.84	.096	11	.099	12	.10	12
Rayon	1.30	.11	8	.11	8	.12	9

TABLE II. EFFECT OF PRESSURE ON RECOVERY OF STAPLE

Fiber	Pressure (p.s.i.)	Initial height (in.)	15-Min. recovery (in.)	(%)	2-Hr. recovery (in.)	(%)	24-Hr. recovery (in.)	(%)
Nylon	10,000	1.20	1.00	83	1.10	92	1.20	100
	100,000	1.00	.90	90	.92	92	.96	96
Saran	10,000	.80	.58	72	.80	100	→	
	100,000	.80	.80	100	→			
Wool	10,000	1.10	.44	40	.51	46	.66	60
	100,000	1.00	.31	31	.42	42	.52	52
Orlon acrylic fiber	10,000	1.20	.39	32	.45	38	.58	48
	100,000	1.20	.20	17	.20	17	.22	18
Dacron polyester fiber	10,000	1.20	.24	20	.27	22	.30	25
	100,000	1.10	.16	14	.17	16	.20	18
Dynel	10,000	1.30	.23	18	.25	19	.27	20
	100,000	1.20	.14	12	.15	12	.15	12
Acetate	10,000	1.10	.11	10	.11	10	.11	10
	100,000	1.10	.10	9	.10	9	.10	9
Rayon	10,000	1.30	.13	10	.15	12	.17	14
	100,000	1.30	.11	8	.11	8	.12	9

heights were less than 0.2 in. could be measured on a spring-loaded Ames gage; those whose recovered heights were greater than this, being too compressible for the Ames gage, were measured with a ruler.

Recovered heights of the staple pellets were recorded in inches and converted into percent of the initial height. The initial height of the staple was measured at the beginning of an experiment in the compression cylinder under a total load of 1 g.

Results and Discussion

Table I shows the ranking of a number of fibers on the basis of their recovery from 100,000 p.s.i. Rubber fibers and saran fibers show 100% recovery from these high compressional forces. It will also be noted that the fibers with high recoveries have low initial heights, indicating poor bulk. Nylon also recovers very well from high compressional forces. Three acrylic fibers—*Orlon* * acrylic fiber, *Acrilan* † acrylic fiber, and Dynel—have high initial heights; this is in agreement with their favorable bulking and covering-power performance in fabrics.

Several experiments were carried out over a range of pressures in order to investigate the effect of

* DuPont trademark.
† Chemstrand trademark.

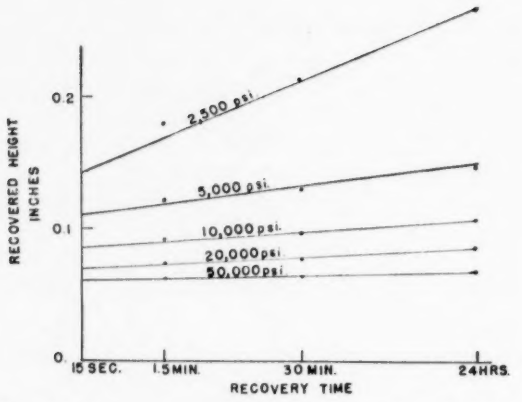


FIG. 2. *Recovery* vs. *time of recovery for absorbent cotton.*

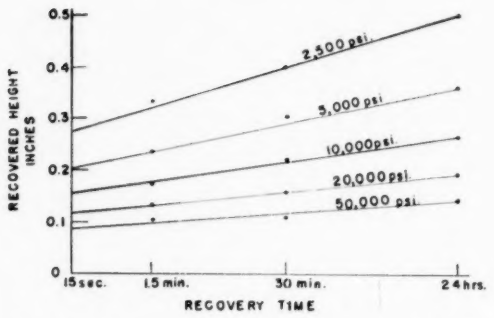


FIG. 3. *Recovery* vs. *time of recovery for* Dacron *polyester fiber.*

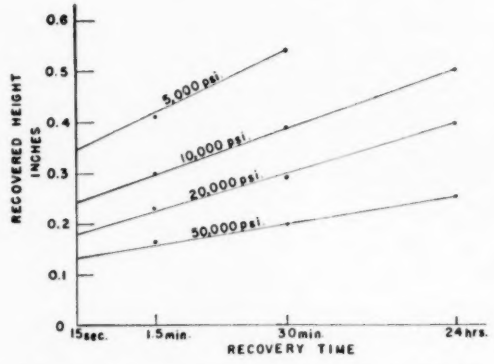


FIG. 4. *Recovery* vs. *time of recovery for* Orlon *acrylic fiber.*

pressure on the ranking of the fibers. Table II summarizes the results, and brings out two important points: (*1*) fibers recover better from lower compressional forces; and (*2*) the recovery rankings at 10,000 and 100,000 p.s.i. are in the same order. However, the sample of *Orlon* acrylic fiber rates slightly better in recovery from 10,000 p.s.i., relative to the other fibers, than it does from 100,000 p.s.i. Figures 2, 3, and 4 summarize the recoveries of cotton, *Dacron* * polyester fiber, and *Orlon* over a range of pressures. The curves of recovery *vs.* time of recovery are practically logarithmic over the experimental range of this investigation.

In Part I were postulated several processes that could be involved during compression of the fibers and which could explain their recovery behavior. They were: (*1*) failure of recovery due to stressing beyond the breaking stress; (*2*) failure of recovery due to high frictional forces between fibers; and (*3*) failure of recovery due to interfiber fusion. It is the intent of this paper to show that stressing beyond the elastic limit and breaking strength is the major reason for poor fiber recovery, and that surface adhesional and structural effects are secondary.

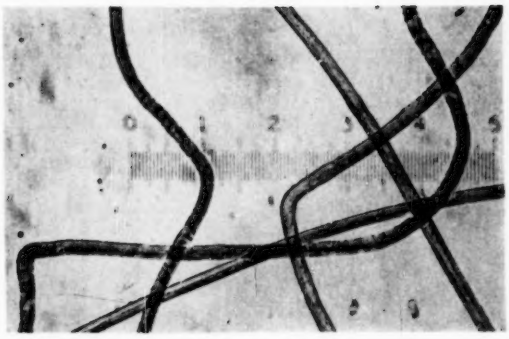
Most of the fibers which rated high in this test (see Table I) were elastomeric. This fact is the first indication that the fibers which recover well from high strains also recover well from the compressional test. Figure 5 shows photomicrographs of fibers which have been pressed under 50,000 p.s.i. There is evidence from the photomicrographs that some rayon fibers were actually broken in the process. Also, the crushed aspect of the fibers leaves no doubt that they were strained beyond their elastic limit. The effect of the pressure on *Dacron* polyester fiber is the most pronounced; one can almost see the impressions of all the fiber crossovers on each *Dacron* fiber in the picture. The recovery of the nylon sample in this figure is remarkable, especially by contrast with the others.

For textile apparel uses, where strains are much less severe, this relation between *Dacron* and nylon is exactly reversed. *Dacron* is one of the most resilient fibers in apparel.

With this indication of the importance of high strains for correlation with the results of the compression test, a series of fibers were tested on an electronic tensile tester, similar to the Instron, for recovery from 20% elongation. Table III shows that the correlation between the two tests is excellent. With the exception of *Vicara* * protein fiber, the

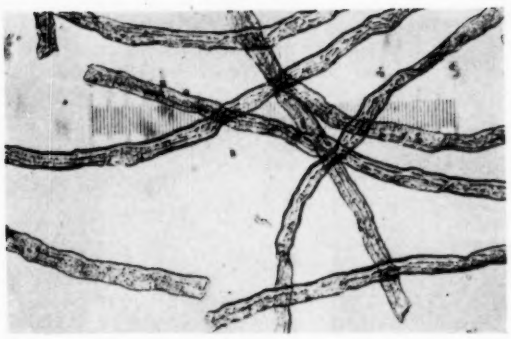
* DuPont trademark.

* Virginia-Carolina Chemical Corp. trademark.

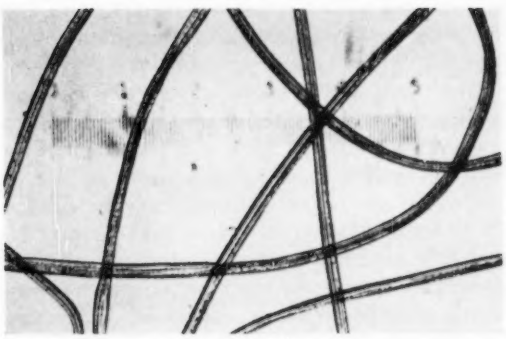


Nylon

Dacron *polyester fiber*



Rayon



Uncompressed control

FIG. 5. *Photomicrographs of staple after compression at 50,000 p.s.i.*

order in each test is the same. This, then, is rather conclusive evidence of the importance of high fiber strains as the explanation of the test. It will be remembered that rubber fibers show the best recovery in the test. These rubber fibers also have low apparent second-order transition temperatures, as do both nylon and saran. With reference to Table III, it will be noted that these fibers are rated in approximately inverse order of their apparent second-order transition temperatures.

TABLE III. CORRELATION OF STAPLE RECOVERY FROM HIGH COMPRESSION WITH FIBER RECOVERY FROM 20% STRETCH

Order of decreasing recovery of staples from 10,000 p.s.i.	Order of decreasing recovery of fibers from 20% stretch
rubber	rubber
elastic nylon	elastic nylon
nylon	nylon
saran	
wool	wool
Orlon acrylic fiber	*Orlon*
Vicara protein fiber	
Dynel	Dynel
Dacron polyester fiber	*Dacron*
	Vicara
acetate	acetate
rayon	rayon

One further set of experiments that indirectly adds more weight to the high strain theory is summarized in Table IV. Pellets removed from the compression chamber were given various aftertreatments in an attempt to improve their recoveries. Some of these attempts were successful. For example, compressed pellets of *Dacron* polyester fiber recover twice as much in air at 100°C as they do at room temperature. The effect of hot air on the recovery of Dynel is even more spectacular. However, hot air has no appreciable effect on acetate, Vicara, or rayon. This effect of heat on the recovery of *Dacron* and Dynel fibers suggests that the loss of form is not permanent, but that recovery is merely delayed by a high internal viscosity. It might be predicted that higher tempera-

TABLE IV. EFFECT OF AFTERTREATMENTS ON PELLETS WHICH HAD BEEN COMPRESSED TO 100,000 P.S.I.

Fiber	Aftertreatment	72-Hr. recovery Control (in.)	Control (%)	Treated (in.)	Treated (%)
Rayon	Hot air at 100°C for ½ hr.	0.11	15	0.12	17
Acetate	Hot air at 100°C for ½ hr.	.10	12	.11	13
Dacron polyester fiber	Hot air at 100°C for ½ hr.	.16	21	.26	35
Dynel	Hot air at 100°C for ½ hr.	.14	16	.57	64
Vicara protein fiber	Hot air at 100°C for ½ hr.	.20	28	.20	28
Rayon	Water, 5 min., 100°C	.081	12	.72	100
Rayon	Water, ½ hr., R.T.*	.094	13	.72	100
Rayon	Ethyl alcohol, 15 min., R.T.	.092	13	.11	15
Rayon	CS_2, 15 min., R.T.	.080	11	.085	12

* R.T. = room temperature.

tures would increase the recovery of certain fiber types as long as the recovery temperature is kept well above the apparent second-order transition temperature, but below the melting point.

One might also predict that any swelling agents applied to the fibers after compression might aid the fiber recovery. That this is true was demonstrated with the application of water to rayon at 25°C and 100°C. Water is known to swell rayon, and Table IV shows that the recovery goes from a low of 15% to 100% with the application of water. Figure 6 shows photographs of compressed rayon staple immediately after immersion in water and 30 sec. later; it emphasizes the striking effect of water on the recovery of rayon staple.

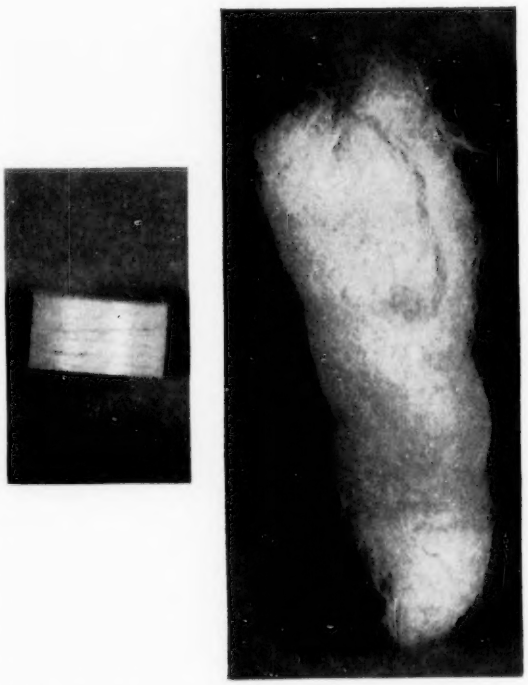


FIG. 6. *Effect of water on recovery of compressed rayon staple.* Left—*Immediately after immersion in water.* Right—*30 sec. later.*

To determine whether surface friction or fusion was of primary importance, a search was made for certain finishes to change the surface characteristics and thereby alter the compressional recoveries of the staple samples. *Dacron* and rayon fibers were treated with rubber cement, graphite, paraffin oil, and silicone oil. Little or no improvement was obtained in any of these tests. These results are shown in Table V. No evidence of fusion was ever noted in the microscope examinations. These results demonstrate that surface friction and fusion are probably of secondary importance to the explanation of this investigation.

In continuing attempts to change the behavior of fibers to these high compression stresses, several other experiments were tried. The use of swelling agents and heat as pretreatments were not effective. As another approach, the effect of filament denier on recovery was briefly scouted with *Dacron*. The results, shown in Table VI, indicate that the compressional recovery of *Dacron* from 100,000 p.s.i. is invariant with changes in filament denier. Finally, blends of staple were investigated under these high compressional forces. Results are tabulated in Table VII. It is apparent that the recovery of rayon can be improved by blends with other fibers which, alone, show excellent recovery from 100,000 p.s.i. Rubber, elastic nylon, nylon, saran, and wool all improve the recovery of the rayon staple in this test. The amount of improvement in the recovery of rayon is directly

TABLE V. EFFECT OF SURFACE TREATMENTS ON STAPLE RECOVERY (PRESSURE OF 100,000 P.S.I.)

	Initial height (in.)	15-Min. recovery (in.)	(%)	2-Hr. recovery (in.)	(%)	24-Hr. recovery (in.)	(%)
Rayon control	0.92	0.08	9	0.09	10	0.11	12
Rayon with rubber cement	.91	.09	10	.10	11	.15	16
Orlon acrylic fiber, control	.80	.13	16	.15	19	.16	20
Orlon, scoured	.75	.13	17	.14	19	.14	19
Dacron polyester fiber, control	.70	.12	17	.13	19	.14	20
Dacron, scoured	.70	.11	16	.11	16	.11	16
Dacron, graphite	.79	.14	18	.15	19	.18	23
Dacron, benzene and paraffin oil	.72	.14	19	(.15) interpolated	(21)	.17	24
Dacron, silicone oil and Tetralin (tetrahydronaphthalene)	.71	.13	18	.14	20	.16	23

TABLE VI. EFFECT OF FILAMENT DENIER ON RECOVERY OF *Dacron* POLYESTER STAPLE (PRESSURE OF 100,000 P.S.I.)

Filament denier	Initial height (in.)	15-Min. recovery (in.)	(%)	2-Hr. recovery (in.)	(%)	24-Hr. recovery (in.)	(%)	72–96-Hr. recovery (in.)	(%)
4.5	0.75	0.13	17	0.14	19	0.15	20	0.15	20
7	.70	.12	17	.13	19	.14	20	.14	20
10	.72	.12	17	.13	18	.14	19	.15	21
13	.77	.13	17	.14	18	.14	18	.15	19
21	.74	.13	18	.14	19	.15	20	.15	20
33	.73	.12	16	.13	18	.14	19	.15	19

TABLE VII. RECOVERY OF STAPLE BLENDS (PRESSURE OF 100,000 P.S.I.)

Fibers	Weight (%)	Initial height (in.)	15-Min. recovery (in.)	(%)	2-Hr. recovery (in.)	(%)	24-Hr. recovery (in.)	(%)
Rayon	100	0.72	0.084	12	0.087	12	0.11	15
Rayon/rubber	90/10	.70	.15	21	.16	23	.19	27
Rayon/rubber	75/25	.72	.20	28	.22	31	.25	35
Rayon/rubber	50/50	.70	.27	39	.27	39	.29	41
Rayon/nylon	75/25	.80	.17	21	(.21)	—	.25	31
Rayon/elastic nylon	75/25	.90	.18	20	.19	21	.21	23
Rayon/wool	75/25	.80	.12	15	(.15)	—	.19	24
Rayon/saran	75/25	.80	.10	13	.11	14	.13	16
Rayon/*Dacron* polyester fiber	75/25	.96	.10	10	.10	10	.13	14
Dacron	100	.71	.12	17	.13	18	.16	23
Dacron/rubber	75/25	.61	.21	34	.22	36	.23	37
Dacron/nylon	75/25	.72	.19	26	.27	38	.30	42
Dacron/saran	75/25	.60	.14	23	.16	27	.16	27
Dacron/wool	75/25	.69	.15	22	.16	23	.19	28

related to both the amount of the other fiber and the extent of recovery of the other fiber.

Table VIII summarizes a set of experiments carried out under three different conditions of high temperature, as follows: (*1*) pressed at 25°C, recovered at 100°C; (*2*) pressed at 100°C, recovered at 100°C; and (*3*) pressed at 100°C, recovered at 25°C. In every case, the recovery of the fibers decreased going from condition (*1*) to condition (*3*). These data would be of value in predicting fiber behavior under these compressions and temperatures if such conditions were met in service—*e.g.*, filter presses or packing glands. If the pressures and temperatures are different from those just described, then it is a simple step to alter the testing conditions to match the service conditions.

This last discussion leads to the final point concerning the usefulness of the results. Like most other tests, the conditions of testing may vary with the particular end-use. It is always important to ad-

TABLE VIII. EFFECT OF TEMPERATURE ON STAPLE RECOVERY (PRESSURE OF 100,000 P.S.I.)

Fiber	Pressed at	Recovered at	Initial height (in.)	15-Min. recovery (in.)	15-Min. recovery (%)	2-Hr. recovery (in.)	2-Hr. recovery (%)	24-Hr. recovery (in.)	24-Hr. recovery (%)
Nylon	25°C	100°C	1.30	0.74	56	0.75	58	0.76	58
	100	100	1.20	.30	25	.32	26	.29	24
	100	25	1.00	.17	15	.18	16	.18	16
Wool	25	100	1.30	.59	45	.64	49	.64	49
	100	100	1.40	.18	12	.20	14	.16	12
	100	25	1.10	.16	14	.16	14	.18	16
Dacron polyester fiber	25	100	1.10	.34	30	.36	32	.36	32
	100	100	1.20	.13	11	.14	12	.14	12
	100	25	1.00	.11	10	.11	10	.11	10
Rayon	25	100	1.20	.11	9	.11	9	.12	10
	100	100	1.20	.08	7	.08	7	.08	7
	100	25	1.30	.08	6	.08	6	.08	6

just variables to match those encountered in service, with the possible exception of the time variable. For example, in this compression work, it would be improbable that all who might use this test would find the same conditions applicable to their problem. There are a wide range of temperatures, pressures, immersion media, etc., which might meet a number of service needs.

The general applications of the test fall into process and product categories. From the process point of view, Part I explored some relationships of this test to predicting textile processability. Since pressures between fibers during processing can be quite great, the test may indicate whether excessive fiber breakage, lateral fiber damage, or longitudinal fiber stretching will take place. A second variation of processing usefulness, this time in a more positive direction, is the purposeful application of pressure before carding. It has been shown in our laboratories that fibers which card or spin poorly can often be made to show good textile processing performance by application of high pressures to the staple package or bale at the outset of the textile operations.* Whether this technique will work or not can be predicted by small-scale high compression testing. The increased processability is inversely proportional to the recoveries from compressions of 100,000 p.s.i. in the laboratory test. By reference to the photomicrographs of pressed fibers in Figure 5, one can readily explain the processability correlation. The roughened fiber surfaces probably allow for increased mass cohesion between fibers. The roughened surface is similar to a microcrimp.

For product usefulness, reference is made to the correlation between staple recoveries from high compression and fiber recoveries from 20% elongation. Higher or lower pressures during the compression cycle would probably correlate with other fiber strains. Wherever the fibers encounter high strains in service—whether in apparel, household furnishings, or industrial fabrics—this test will help predict the performance of fibers for that end-use. The high compression test is rapid; for that reason, it offers a substantial time advantage over fabric preparation and end-use testing.

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The Sorption of Hydrogen Chloride by Wool*

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Introduction

Although the sorption of acids by wool from aqueous solutions of the acids has been measured by a number of investigators, no one seems to have investigated the sorption of the dry acids by wool. The combination between gaseous hydrogen chloride and a number of proteins, particularly collagen in the form of hide powder, has been studied, but wool was not included in any of these experiments. Bancroft and Barnett [1] studied the sorption of hydrogen chloride by zein, casein, arachin, edestin, fibrin, and gliadin, and claimed to have demonstrated the existence of compound formation between the protein and the hydrogen chloride by the presence of isobaric regions in the sorption isotherm, except for zein which showed no such constant pressure region. Belden [3] working with gelatin, Beek [2] with collagen, and Tsai and Hsaio [19] with hide powder all found evidence for compound formation between the protein and hydrogen chloride. Czarnetsky and Schmidt [9] also investigated the sorption of hydrogen chloride by a number of proteins, including silk fibroin, and claimed to have shown the existence of definite compounds with partial pressures of a few millimeters of mercury. However, Parks and Melaven [15] could find no evidence of compound formation in their results, and they attributed the results obtained by the other investigators to insufficient time having been allowed for equilibrium to be reached.

More recently, Benson and Seehof [4] measured the sorption of hydrogen chloride by egg albumin at two temperatures, and, although isobars were detected in the low pressure range, these were not taken as a necessary indication of compound formation since they were time-dependent. Nevertheless, some of the hydrogen chloride appeared to be irreversibly held by the protein. This amount, which could be reproduced in several experiments, was about one milliequivalent per gram of protein, a figure which is close to that found for the combining capacity of the protein in acid solutions. Recent experiments carried out by Green [11] indicated compound formation between dry hydrogen chloride and silk, collagen, and elastin.

The sorption of acids by wool from aqueous solutions is generally regarded as a back-titration of the free carboxylic groups present in the protein. However, Steinhardt, Fugitt, and Harris [18] assumed that some undissociated acid is also taken up, in order to explain the large uptake of certain weak acids which they observed. Elöd and Fröhlich [10] also mentioned the possibility of undissociated acid being sorbed in order to explain the high sorption values they obtained with solutions of low pH.

If, indeed, undissociated acid is sorbed by wool, the forces of attraction responsible for this sorption should also cause dry hydrogen chloride to be sorbed by the wool. The experiments described here form part of a program undertaken to learn more of the interaction between wool and acids.

Apparatus and Methods

The wool samples were suspended at the lower end of quartz fiber spiral balances placed in four wide glass tubes. These were closed at their upper ends by ground glass stoppers to which were fused glass hooks which held the spring balances. The tubes were contained in a closed box which served as an air chamber thermostated to the desired temperature. A horizontal fan at the bottom of the box circulated the air around the tubes and helped to maintain the temperature uniform in the box. The box was provided with windows for observing the length of the quartz spirals, which was measured by means of a cathetometer. A mercury manometer indicated the pressure in the sorption system. The apparatus could be evacuated by a mercury diffusion pump backed by a Hyvac oil pump. A McLeod gage was used to follow the progress of the evacuation. Two 5-liter flasks which could be connected to the sorption tubes were used as reservoirs for the hydrogen chloride. The hydrogen chloride was obtained from a commercial cylinder and claimed to be 99.5% pure.

* This paper is designated N.R.C. No. 2891.

It was further purified by bubbling through concentrated sulfuric acid and over anhydrous aluminum chloride. The gas was collected in a small cylindrical bulb by freezing with liquid air. A further attempt to purify the hydrogen chloride was made by fractionating the condensate. After filling the bulb, the flow of gas from the cylinder was stopped, and the hydrogen chloride was allowed to evaporate into a discharge train consisting of wash bottles filled with calcium chloride and potassium hydroxide, which absorb the gas. When about one-third of the hydrogen chloride in the bulb had been removed, the gas flow was diverted to the reservoirs until these were filled at atmospheric pressure, as shown by a second manometer in this part of the system and which also acted as a safety valve. The excess hydrogen chloride was allowed to evaporate into the discharge train again.

The wool used was of various degrees of fineness. It was cleaned by successive extractions with ether and with alcohol, then rinsed in water, and freed of all vegetable or other extraneous matter by hand. The samples weighed from 0.15 g. to 0.25 g. each. With a cathetometer reading to 0.01 mm. and spiral balances having a sensitivity of more than 1 mm. deflection per milligram weight, the weight of the samples could be determined readily to within $\pm 0.02\%$. All samples were equilibrated to a pH of about 5.0 before use.

The use of mercury in the manometer which indicated the pressure in the sorption tubes offered no difficulty. It was found that any attack of the mercury in the manometer was very slow, and the manometer could be used for several weeks before a film formed on the surface interfered seriously with the pressure measurements.

In the initial experiments, phosphorous pentoxide was used as a drying agent, but it was later replaced by aluminium chloride because it was found that the phosphorous pentoxide absorbed an appreciable amount of hydrogen chloride and slowed up the condensation in the freezing bulb. Moreover, the reaction with phosphorous pentoxide may possibly give rise to vapors of phosphorus compounds, which might interfere with the sorption determinations [6].

Results

Two series of sorption determinations were carried out at 28.7°C. In the first series, four samples of wool with a mean fiber diameter of 23.0 μ were used, while in the second series, two of the samples had a mean diameter of 20.6 μ and the other two a mean diameter of 36.9 μ. The isotherms obtained are given in Figure 1. In the first experiment, the sorption was measured at eight different pressures up to 65.1 cm. of mercury, after which desorption was carried out in five steps. Then the pressure was again brought up to 63.3 cm., after which the wool was desorbed once more. In the last step of the first desorption, the apparatus was pumped out for 140 hrs., yet 1.7 millimoles of hydrogen chloride still remained sorbed per gram of wool. In the second desorption, the temperature was raised stepwise in an attempt to reduce the residual amount sorbed, but even after 300 hrs. of evacuation, 44 hrs. of which were at 75°C, the highest temperature used, there were still 1.4 millimoles of the gas sorbed per gram of wool. At this point, the samples were removed and rinsed with distilled water until no more acid could be removed. The samples were then dried in a vacuum desiccator over magnesium perchlorate, and weighed in closed weighing bottles. The final weights of the wool samples were within 0.2% of the initial dry weights. After the experiment, the wool felt somewhat harsher and was slightly discolored (yellowish tinge), but otherwise showed no visual signs of decomposition.

In a third experiment, an isotherm at 42.5°C was obtained with samples of the same wools as used in the second experiment. Due to unavoidable circumstances, the isotherm could only be determined up to

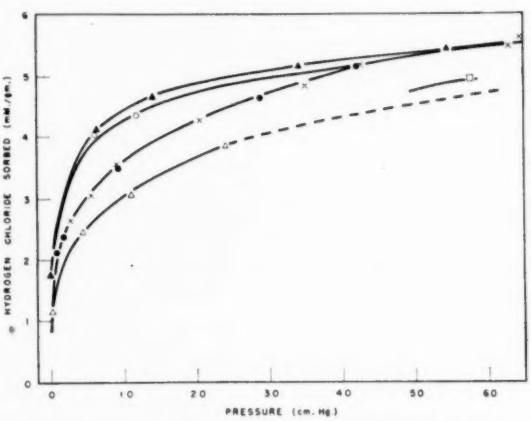

FIG. 1. *Sorption and desorption isotherms of hydrogen chloride on wool.* △ = *Sorption at 42.5°C.* □ = *Sorption at 32°C.* ×, ● = *Sorption at 28.7°C.* ○, ▲ = *Desorption at 28.7°C.*

a pressure of 24 cm. of mercury. The results obtained are also given in Figure 1. The dotted portion of the curve was extrapolated from the ratio hydrogen chloride sorbed at 27.8° to that at 42.5°, which appeared to be constant for the lower points.

Another experiment, in which wools having mean fiber diameters of 23.0 μ, 26.4 μ, 30.0 μ, and 36.9 μ were used, was carried out for the purpose of determining the rate of diffusion of the hydrogen chloride in the wool. In this case, an attempt was made to maintain the pressure reasonably constant by closing off the reservoirs at intervals, refilling them, and allowing additional gas to flow into the sorption tubes to balance that sorbed by the wool. In this way it was possible to maintain the pressure to 57.6 ± 0.2 cm. of mercury. The temperature for this experiment was 32.0° ± 0.2°C. The initial sorption, which was rapid, was followed closely by taking frequent readings during the first day of sorption. On desorption, evacuation was carried out for 286 hrs., after which the loss became immeasurably small. However, the amount of hydrogen chloride remaining in the wool was still 1.63 mM./g. The amount of gas sorbed at what was considered the equilibrium point (after 165 hrs.) is included in Figure 1, and falls between the 27.8° and 42.0°C results, as might have been expected.

In another experiment, an attempt was made to measure the sorption at a temperature of about 4°C, maintaining the pressure at 49.4 ± 0.2 cm. of mercury. The low temperature was reached by placing solid carbon dioxide in a wire basket around the fan at the bottom of the air bath. The fan was operated by a thermostat placed at the level of the sorption tubes, and circulated the cold air only when the temperature rose above that desired. Enough carbon dioxide could be placed in the basket to last overnight. It was found, however, that the temperature had a tendency to rise slightly when the carbon dioxide was nearly exhausted, so that over long periods the temperature could only be considered constant to within ± 1.0°C, exception made of course for the short periods, a minute or so, during which the door was opened for refilling the basket with solid carbon dioxide. It is very doubtful that equilibrium was greatly disturbed by these short interruptions when the temperature rose several degrees, as the temperature dropped immediatly on closing the door and the fan was set in operation by the thermostat. After equilibrium at 4°C had been reached, the temperature was lowered to − 1°C and maintained to within ± ½° for a few hours, after which a reading was taken. The temperature was then allowed to rise a few degrees, and readings were again taken after a few hours. In this way, readings at various temperatures up to room temperature were taken; the results are given in Table I. It should be realized that whenever a reading was taken after the temperature had been raised, it represented a point on a desorption curve,

TABLE I. HYDROGEN CHLORIDE SORBED BY WOOL AT VARIOUS TEMPERATURES AND PRESSURES

Temperature (°C)	Pressure (cm. Hg)	Hydrogen chloride sorbed* Measured (mM./g.)	Calculated for 49½ cm. pressure (mM./g.)
4	49.5	6.82	—
7	49.5	6.76	—
2	49.5	7.02	—
27	49.5	5.32	—
After desorption		1.16	
4	29.5	5.97	6.77
−1	29.5	6.14	6.95
4	38.5	6.14	6.52
3	38.5	6.08	6.46
6½	53.0	6.50	6.40
0	53.0	6.55	6.45
1	53.0	6.63	6.53
4	53.0	6.80	6.70
26½	50.5	5.31	5.29
10½	50.5	6.05	6.03
28.7	49.5	5.28	—
42.5	24.0	3.85	4.59
32.0	57.7	4.95	4.78

* The results are given above in the order in which they were determined experimentally. The last three rows of figures refer to the results of experiments 1, 2, and 3, respectively, and are included for purpose of comparison.

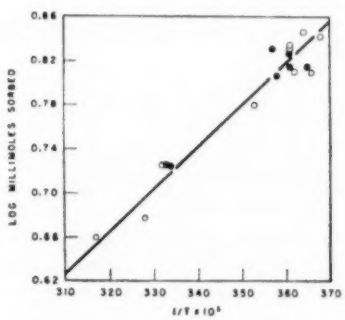

FIG. 2. *Log amount hydrogen chloride sorbed at a pressure of 49½ cm. of mercury as a function of the reciprocal of the absolute temperature.* ○ = *Sorption.* ● = *Desorption.*

since sorption decreased with increased temperature. However, owing to the small temperature intervals involved in most cases, the differences between sorption and desorption results cannot be very great. It will be noticed from the table that in a few cases changes were also made in the pressures. Although the time allowed for each reading was undoubtedly too short to enable equilibrium to be reached, and these figures are not true equilibrium values, the errors cannot be very large since the changes between readings were small in any case. Nevertheless, these values were used to calculate the heat of sorption. A plot of log amount sorbed *versus* log pressure gave roughly the same slope at the various temperatures, and this relation was used to convert all sorption results to a common pressure of 49.5 cm. of mercury. These results are given in the fourth column of Table I, and are plotted as log amount sorbed against $1/T$ in Figure 2, from which ΔH was calculated to be -1750 cal. This is probably within 5% of the correct figure.

Discussion

The procedure followed in the present experiments was not devised to determine whether there is formation of a definite compound between wool and hydrogen chloride. However, if one applies the phase rule as other investigators have done, then the results indicate that if there is a compound formed, its vapor pressure must be very low. Any compound with an appreciable vapor pressure should have been detected in the absorption isotherm at 28.7°C when the first point was determined with a gas pressure of 8.3 mm. of mercury at the start and a final pressure of 0.9 mm. after the wool had absorbed over 5% hydrogen chloride. Any compound formed would therefore have a vapor pressure of less than 0.9 mm. of mercury, since the continuous nature of the isotherm above this pressure would rule out any higher vapor pressure. It should be noted, however, that such reasoning is based on the assumption that there are two independent solid phases in the system. It is questionable whether this assumption is valid when dealing with solid proteins. There might be justification for considering the compound and the free protein as two separate phases if the chemical potential or free energy of one phase were not affected by the other, but whether this holds for solid proteins is open to question. It implies that the affinity of the "free" protein is not affected by the combination of the hydrogen chloride with the remainder of the protein chains. This is very improbable in view of the interaction of the various polar groups in the protein chains. It might be better, therefore, to consider the protein with sorbed hydrogen chloride as one solid phase, in which case it would be possible to have compound formation at various pressures for a given temperature. Other considerations lead one to expect not one but several constant pressure plateaus during the hydrogen chloride sorption if compound formation is reflected by such constant pressure regions. If compound formation is between the hydrogen chloride and the side-chains of the basic amino acids—arginine, histidine, and lysine, not to mention proline and tryptophane—then one would expect three different constant pressure regions, one corresponding to each of the compounds formed. Any additional grouping involved in compound formation would add another constant pressure region to the sorption isotherm. It should be noted that the dissociation pressure of ammonium chloride is very low at room temperature, and if the dissociation pressure of the compounds formed between hydrogen chloride and the basic groups of the protein is of the same order, the formation of the compounds will not be detected unless the experiments are specially devised to indicate such low pressures.

One could reason as Green has done [11], and conclude that a compound is formed because it is very difficult to remove all the sorbed hydrogen chloride by evacuation. However, if the amount of hydrogen chloride expected to be bound to the wool is calculated from the serine and threonine content, the two amino acids with which hydrogen chloride combines according to Green, one gets 5.6%, whereas in the experiment carried out at low temperature (~ 4°C), the residual hydrogen chloride was only 4.2% of the weight of the wool after 260 hrs. evacuation at room temperature and the samples were still losing weight, although very slowly ($< 0.1\%$ per day).

That there is some attack of the wool by the hydrogen chloride is almost certain. The wool acquired a yellowish tinge during the sorption, and an alkali solubility test [17] carried out on the samples after the hydrogen chloride had been removed, except for the small amount remaining after long evacuation, indicated extensive damage since the wool lost about 75% of its weight in the alkaline solution. However, the solubility test was carried out several days after removal of the samples from the sorption tubes; the wool had ample opportunity to absorb water from

the atmosphere during the interval, and this may have contributed to the damage indicated by the test.

It is possible to remove all residual chloride from the wool by rinsing with distilled water. This was interpreted by Green [11] as an hydrolysis of the chloride compound whereby hydrogen chloride is liberated and the hydroxyl group of the original amino acid is re-formed. If this explanation is correct, it should not result in any appreciable damage of the wool. If damage does occur during absorption of dry hydrogen chloride, it is surprising to find that the second sorption isotherm obtained at 28.7°C, after the desorption following the first sorption, coincides within experimental error with the first isotherm.

The hysteresis noted during sorption and desorption may very well be explained by the mechanism suggested by Cassie [7] for a similar effect in the sorption of water. The sorption of hydrogen chloride is no doubt accompanied by a swelling of the wool fibers, and the same mechanical restraints and slow recovery of the wool on desorption that were used by Cassie to explain the hysteresis of the water sorption and desorption process may also be used to explain the hysteresis for any other substance which produces a swelling on absorption. The pressures used in the present experiments cover only a very low region of the relative pressure range of hydrogen chloride since its vapor pressure at 28.7°C is about 51 atmospheres. Even at the highest pressure used herein, the relative pressure is only 0.017, so that there can be no question of using a condensation phenomenon to explain the hysteresis noted.

The isotherms for hydrogen chloride sorption on wool appear to follow the Freundlich equation better than the Langmuir equation. Figure 3 gives the 28.7°C isotherm plotted to show the Freundlich relation, while Figure 4 gives the same data plotted according to the Langmuir formula. Whereas the latter represents the experimental results for the higher pressures, the Freundlich equation expresses fairly well the results over a wider range of pressures for the 20.6 μ wool and over the whole range investigated for the 36.9 μ wool. There is no apparent explanation for the difference in behavior of these two wools at the low pressures. Benson and Seehof [4] also found that the sorption of hydrogen chloride by egg albumin obeys the Freundlich equation. They pointed out that this is to be expected if the sorption sites have energies of sorption which are distributed with an exponential frequency, a fair assumption for the polar groups of proteins.

At the low relative pressures with which we are dealing here we are so far removed from saturation that it is not possible to make an estimate of the surface available to hydrogen chloride, but one can at least calculate the minimum surface available from the surface occupied by the gas sorbed. If one takes the area covered by one hydrogen chloride molecule as 11.6 sq. Å. (calculated from the density of solid hydrogen chloride at 0°C), then one millimole of the gas will cover at least 70 sq. m. and the 7.1 millimoles sorbed at − 1°C will require a surface of about 500 sq. m. per gram of wool.

The 28.7°C isotherm allows us to make a rough estimate of the free energy change involved in the hydrogen chloride sorption by the wool. A graphical integration of the area under the *a/p versus p* curve

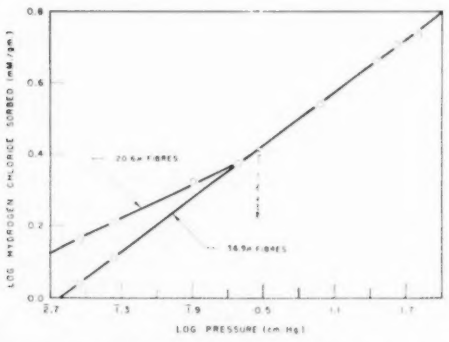

FIG. 3. *Results of the 28.7°C isotherm plotted to show the Freundlich relation.*

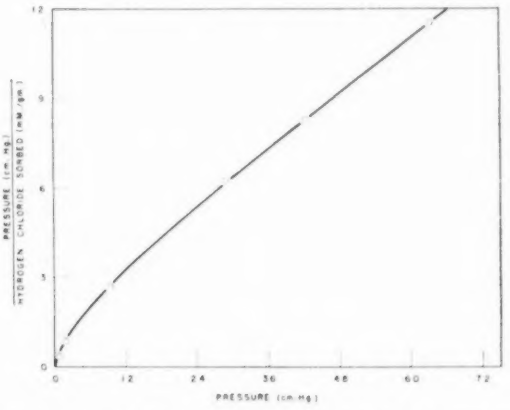

FIG. 4. *Results of the 28.7°C isotherm plotted according to the Langmuir equation.*

up to 60 cm. pressure, where p is the pressure and a the amount of gas sorbed, gives us a free energy change of -1760 cal. (corrected to 25°C) or 105 ergs per sq. cm. of surface. This is much larger than the free energy change involved in the water sorption by wool as calculated by Bull [5] and by Rowen and Blaine [16]. These investigators' results agree fairly well, and give ~ 975 cal. for the free energy change or ~ 64 ergs/sq. cm. when the wool is covered with a monolayer of water molecules. The surface covered by the water at this point has been calculated to be 206 sq. m./g. by Rowen and Blaine [16] and 233 sq. m./g. by Bull [5]. The much larger surface found covered with hydrogen chloride indicates that many more groups are involved in the hydrogen chloride sorption than are responsible for the sorption of water molecules.

If we now consider the polar groups that may possibly attract hydrogen chloride, we have per gram of wool a little more than one milliequivalent of basic groups due to the presence of arginine, lysine, histidine, proline, and tryptophane. If the hydroxyl groups of serine and threonine also react, as claimed by Green [11], this will account for more than 1.5 milliequivalents. It is evident from the amount of hydrogen chloride sorbed by wool in our experiments that other groups are also active. These must be the peptide groups, of which there are about 8.8 milliequivalents per gram, making a total of 11.3–11.4 milliequivalents of available sites for sorption of hydrogen chloride. Whether the amount of gas sorbed by wool can approach this amount still needs to be determined by experiments at lower temperatures and for higher partial pressures than those used in the experiments reported here.

As pointed out earlier, the experiment at 32°C was specially designed to measure the rate of diffusion of hydrogen chloride through wool. In order to calculate the rate of diffusion from the results, the method suggested by Crank [8] was used. These calculations are applicable whenever we have diffusion with a nonlinear adsorption of the diffusing substance and where the rate of sorption is determined by the rate of diffusion. It has been shown that the adsorption of hydrogen chloride by wool is nonlinear, and, as regards the rate of sorption, it is fair to assume that this is rapid in comparison with the rate of diffusion. The results obtained bear this out. Green [11] assumed that the sorption of hydrogen chloride by silk and collagen proceeds in two ways: firstly, a rapid

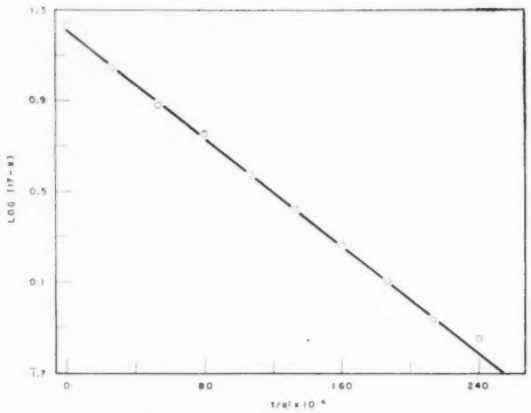

FIG. 5. *First-order reaction rate equation applied to the rate of sorption results at 32°C.* x = *Amount of hydrogen chloride* (%) *sorbed at time* t (*min.*). a = *Radius of fibers* (*cm.*).

sorption by the basic groups of the protein; and, secondly, a slow reaction with the hydroxyl groups of serine and threonine. However, the sorption isotherms he obtained showed no signs of the discontinuity that might have been expected as the result of two processes differing greatly in speed. Moreover, the linear relationship he claimed to have obtained between log $(a - x)$ and time, where a is the total amount of hydrogen chloride combined at saturation and x is the amount combined at time t, which he used as an indication of the slowness of the reaction, is more illusory than real. The results he obtained for the first day of sorption, during which time an important fraction of the sorbed hydrogen chloride is presumably combined, do not obey the straight-line relation. Green disregarded the slow diffusion of the gas as a possible factor in the slowness of the hydrogen chloride uptake. The linear relation between log $(a - x)$ and t on which Green based his conclusions is not a necessary indication of a reaction of the first order. For example, if our results obtained at 32°C are plotted as log $(17 - x)$ against t, where x is the amount of hydrogen chloride sorbed at time t, a fairly good straight line is obtained, as shown in Figure 5.

In order to calculate the rate of diffusion by Crank's method, use was made of the relation $s = 191\ c^{0.226}$, which was derived from the Freundlich equation interpolated from the results obtained at 28.7°C and 42.5°C. The notation is that of Crank: $s = S/C_o$ and $c = C/C_o$, where S is the amount of hydrogen chloride, expressed as a concentration,

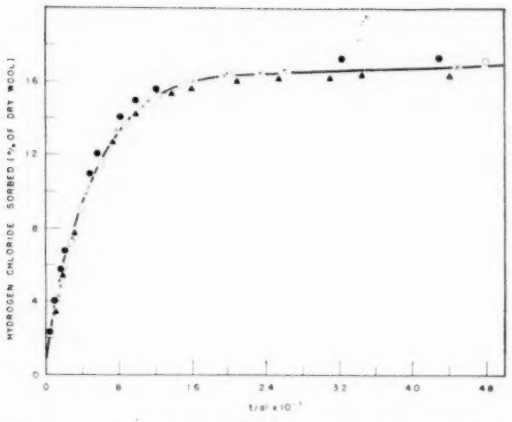

FIG. 6. *Rate of sorption of hydrogen chloride by wools differing in mean fiber diameter.* t = *Time (min.).* a = *Mean radius of fibers (cm.).* a × 10^4 = *18.4,* ●; *15.0,* ○; *13.2,* ×; *11.5,* ▲.

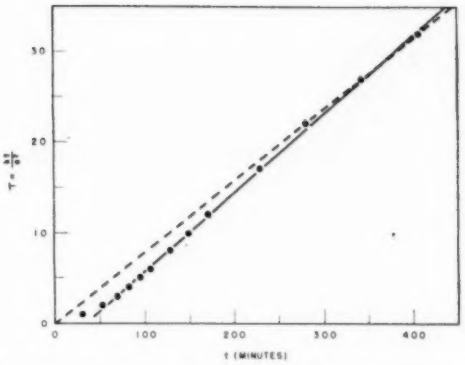

FIG. 7. *Application of Crank's diffusion equation to the 32°C results for the sorption of hydrogen chloride by wool.* t = *Time of sorption (min.).* a = *Mean radius of fibers (cm.).* k = *Diffusion constant.*

sorbed on the active sites, C is the concentration of the free gas in the wool, and C_o is the initial concentration of the hydrogen chloride in the gaseous phase surrounding the wool. The number, p, of concentric shells into which the wool fiber, considered as a cylinder, was divided was arbitrarily chosen as eight. Crank found this to give good results for practical purposes. The calculations become more and more laborious as this number is increased.

Perhaps the best indication that the sorption rate is controlled by the speed of diffusion is the relation between sorption rate and fiber diameter. According to the equation developed by Crank, one should get identical curves when the amount of gas sorbed is plotted against t/a^2, irrespective of the fiber diameter, where t is the time and a is the fiber diameter. Figure 6 shows that the four samples differing in mean fiber diameter did indeed give the same results when plotted in this way. It might be noted that an error is introduced by taking the mean fiber diameter (measured by the projection method) instead of the length-proportioned root-mean-square diameter. But since the ratio between the two (~ 1.025) differs little from one quality wool to another [14], the relationship used above is not invalidated thereby.

In order to calculate the rate of diffusion, values of s were determined for various values of τ in steps of $\delta\tau = 1$, where $\tau = kt/a^2$, k is the coefficient of diffusion, t is the time of sorption, and a is the mean fiber diameter. The values of s thus found were converted into ratios M_t/M_∞, where M_t represents the amount of hydrogen chloride sorbed at time t, and M_∞ is the maximum amount which presumably the wool will absorb under the conditions of the experiment. By referring back to the curve which shows the amount of hydrogen chloride sorbed with time, the time t corresponding to the various values of M_t/M_∞ found above could be determined, and when t is plotted against τ, a straight line should be obtained. The slope of this line gives k/a^2, from which k is obtained directly since a^2 is known. Figure 7 represents the line obtained for the sample of wool with a mean fiber diameter of 36.9 μ. Because of the larger fiber diameter, the sorption *versus* time curve is flatter for this sample than for the other finer wools, and it is possible to extend the relationship between τ and t to greater values of t. For higher values of t than those shown in the figure, the points deviate from the straight line because the sorption curve is very flat and it is difficult to estimate t for a given value of M_t/M_∞ when the latter is greater than 0.85. Moreover, the value of M_∞ is itself an estimate, and for high values of M_t/M_∞ the value of t is greatly affected by a small error in M_∞. This is reflected by the scattering of the observations in Figure 6 for high values of t/a^2. The value of k calculated from the slope of the line in Figure 7 was found to be 4.9×10^{-9} cm.^{2}/sec. Theoretically the line in Figure 7 should have gone through the origin, but it is inherent in the method of finite differences used to calculate s that the values of M_t/M_∞ for small values of τ are too large and therefore also the corresponding values of t. However, the error in k resulting from this is relatively small, as shown by the line drawn

through the origin and the upper three points, which gives a value of 4.4×10^{-9} cm.²/sec. for k.

The initial readings taken to obtain the first point at the final pressure of 0.20 cm. mercury on the 42.5°C isotherm were sufficient to allow an estimate to be made of the diffusion coefficient at that temperature. This was found to be 5.4×10^{-9} cm.²/sec. The activation energy calculated from this figure and that obtained at 32°C is of the order of 2 kg.-cal. for the diffusion process. This value, although subject to a large error, is sufficiently low to indicate that the rate of sorption is diffusion-controlled and is not the result of a slow chemical reaction. The actual diffusion and sorption process is probably not as simple as was assumed in making the above calculations. The wool fiber is not homogeneous, and the several skin layers as well as the cortical cells and any cementing material between them have undoubtedly different diffusion coefficients and possibly different sorptive capacities for hydrogen chloride. Nevertheless, the diffusion coefficient given above is probably of the right order for the fiber as a whole. This diffusion coefficient might be compared with that measured by Lindberg [13] for hydrochloric acid. The diffusion coefficient reported by Lindberg varies from 1.4 to 7.2×10^{-8} cm.²/sec. depending on the method used to clean the wool. The more rapid diffusion of hydrochloric acid is probably due to the high mobility of the hydrogen ion and the electrostatic forces which assist the penetration of the ions.

King [12] calculated the diffusion coefficient for water, methyl alcohol, and ethyl alcohol in horn keratin and for wool in the case of methyl alcohol. The coefficient for water through horn keratin is reported to be $7.5–9.0 \times 10^{-9}$ cm.²/sec., a figure which is very close to ours for hydrogen chloride. The coefficients for methyl alcohol and ethyl alcohol are smaller. King assumed a simple diffusion process in which the diffusion coefficient increased with concentration of the diffusing substance, but Crank [8] pointed out that a diffusion with adsorption can also be represented as a simple diffusion, with an effective diffusion coefficient which is a function of the concentration of the diffusing substance.

Summary

The absorption of hydrogen chloride by wool has been measured at various temperatures ranging from 0°C to 42.5°C, and for various pressures up to 63 cm. of mercury. The isotherms were found to follow the Freundlich equation within the range studied. The large amount of hydrogen chloride sorbed under certain conditions indicates that the peptide band must be responsible for a large part of the gas sorbed. The results are discussed and compared with the results of other investigators obtained with other proteins. The difficulties in determining compound formation are pointed out. The diffusion coefficient of hydrogen chloride through wool at 32°C and 42.5°C has been calculated, and an estimate made of the heat of activation of the process. It is shown that the sorption is diffusion-controlled.

Acknowledgment

The author is grateful to Mr. N. Stolow, who constructed the apparatus and carried out some of the sorption measurements reported.

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Weight Measurement of Yarn Irregularity

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Abstract

To determine the coefficient of variation of certain characteristics in a yarn, such as the weight in constant short lengths, is a long and tedious task when using the standard root-mean-square method of computing the standard deviation. However, this standard deviation can be quite accurately estimated by any one of three short-cut methods described herein—the mean deviation method, the mean range method, and the probit method. The mean itself, by which this standard deviation is divided to get the coefficient of variation, is obtained readily by weighing all the samples together. The standard errors of the coefficient of variation estimated by these short-cut methods are derived, and the efficiencies of the methods are compared with that of the direct root-mean-square deviation method, showing the corresponding sample sizes for the same efficiency.

Introduction

When a yarn is examined minutely from point to point along its length, appreciable variations in the following properties are observed: weight per unit length, diameter, area of cross section, number of filaments in the cross section, strength, and twist angle.

The coefficient of variation of any of the above characteristics may be taken as a measure of the irregularity of the yarn. From practical considerations, however, the coefficients of variation of diameter and weight per unit length appear to be the most important measures* of irregularity. The coefficient of variation of weight per unit length may be called the "weight c.v." of the yarn. In practice, it is found that the determination of the weight c.v. is the simpler operation, and hence this coefficient is often preferred as the measure of irregularity, especially in the case of jute yarns. However, its practical determination is very time-consuming, since in order to get a fairly accurate estimate of the weight c.v., at least a thousand cuttings (of short length) of the yarn have to be examined, and if the individual weights of the cuttings are to be recorded with a chainomatic balance (an ordinary balance of the rider type is unsuitable for such work), the whole work including calculation may take more than 24 hrs. The time required for weighing, however, may be reduced if a quadrant balance of the Schopper type is available, but still the total time required may be more than 12 hrs., and thus the method can hardly be used for routine tests. The technique of estimating weight c.v. should therefore be so modified as to avoid direct weighing of the cuttings. Some such modified techniques are described below. These not only save much of the time necessary for weighing, but also avoid the laborious statistical calculations involved, and are applicable whenever the distribution is normal or fairly normal.

* Truly speaking, the coefficient of variation of strength of extremely short lengths of the yarn is the most important measure of yarn irregularity, but this coefficient is seldom determined, the practical operations being difficult and laborious.

Distribution of Weights of Short Lengths of Yarn

In the case of weights of short lengths of yarn, the distribution of frequency is slightly positively skewed, but this small skewness does not greatly affect the precision of the estimate, especially if the sample is reasonably large. The nature of the frequency distribution of the weight of 2-in. lengths in the case of a 10-lb.* jute yarn is shown (frequencies plotted against group means) in Figure 1, the data being grouped as shown in Table I.

Calculation of Coefficient of Variation

Strictly, the percentage c.v. can only be calculated by (*1*) the root-mean-square deviation method, but for data having the above type of frequency distribution, it may be estimated reasonably accurately by any of the following methods: (*2*) mean deviation method; (*3*) mean range method; (*4*) probit method.

* Weight of 14,400 yds. is equal to 10 lbs.

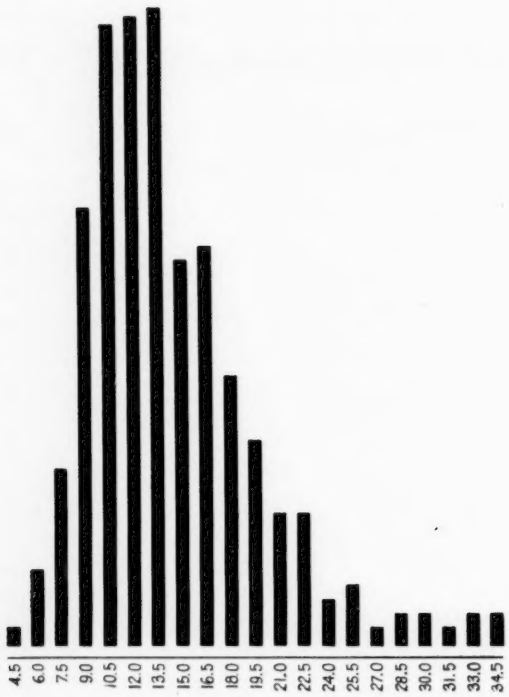

FIG. 1. *Frequencies plotted against group means.*

The theoretical basis of each method is described below, followed by necessary details concerning the practical application of the methods.

Root-Mean-Square Deviation Method

This method is well known and needs no detailed explanation. If $X_1, X_2, X_3, \cdots X_N$ be the individual readings, the estimate of c.v., which is denoted by V, may be obtained from the expression*

$$V = 100\sqrt{N/(N-1)} \cdot \sqrt{(X^2) - (\bar{X})^2}/\bar{X},$$

where N is the total number of readings.

The standard error of V may be stated as

$$\frac{V}{\sqrt{2N}}\sqrt{\alpha^2 + \frac{2V^2}{10^4}},$$

where $\alpha = 1$.

If the frequencies are grouped as shown in Table I, V may be obtained, when correction due to grouping error is small, by evaluating

$$100\sqrt{N/(N-1)} \cdot h \cdot \sqrt{(d^2) - (d)^2}/(A + h\bar{d}),$$

* In this and the following similar expressions for V, the factor $\sqrt{N/(N-1)}$ may be taken equal to 1 when N is sufficiently large.

TABLE I

Group range (mg.)	Frequency
4.0– 5.0	2
5.5– 6.5	10
7.0– 8.0	24
8.5– 9.5	60
10.0–11.0	86
11.5–12.5	87
13.0–14.0	88
14.5–15.5	53
16.0–17.0	55
17.5–18.5	37
19.0–20.0	28
20.5–21.5	18
22.0–23.0	18
23.5–24.5	6
25.0–26.0	8
26.5–27.5	2
28.0–29.0	4
29.5–30.5	4
31.0–32.0	2
32.5–33.5	4
34.0–35.0	4
	600

where A is the arbitrary group mean taken as the origin, h is the group interval, and d is the deviation of any group mean from the arbitrary group mean.

When a very large number of readings must be analyzed, this short-cut method (frequency grouping) proves to be indispensable.

Mean Deviation Method

In the case of a normal distribution, if the number of readings falling below the mean is ν and their sum is ω, and the sum of all the readings is W, the estimated mean deviation may be given by

$$2(\nu W/N - \omega)/\sqrt{N(N-1)}.$$

Now, with this type of distribution, the ratio of the standard deviation to the mean deviation being $\sqrt{\pi/2}$, the estimate of c.v. may be obtained by evaluating

$$250.7\sqrt{N/(N-1)} \cdot \left(\frac{\nu}{N} - \frac{\omega}{W}\right).$$

The standard error of V may be stated as

$$\frac{V}{\sqrt{2N}}\sqrt{\alpha^2 + \frac{2V^2}{10^4}},$$

where [7] $\alpha^2 = 1.14159$, or $\alpha = 1.068$.

Thus, if easy means of finding ν, ω, and W were available, the computation of c.v. would be very simple.

TABLE II

Size of group (n)	Divisor* (D)	Factor (F)
5	2.32593	215.0
6	2.53441	236.7
7	2.70436	258.8
8	2.84720	281.0
9	2.97003	303.0
10	3.07751	324.9
11	3.17287	346.7
12	3.25846	368.3

* The figures in this column are taken from Tippett's original table [6].

TABLE III

Size of group (n)	ρ*	α
2	0.8525	1.511
3	0.8884	1.286
4	0.8798	1.209
5	0.8641	1.175
6	0.8480	1.159
8	—	1.152
10	0.797	1.158
20	0.729	1.234
60	0.639	1.509

* The figures in this column are taken from Pearson's original table [4].

Mean Range Method

If the whole set of readings is arranged at random into a number, m, of groups of equal size, n, and if the range in a group is denoted by R and the sum of the readings by W, the estimate of c.v. may be obtained from

$$V = \frac{(\sum R/m)/D}{W/N} \cdot 100 = \frac{n}{D} \cdot 100 \cdot \frac{\sum R}{W} = F \cdot \frac{w}{W},$$

substituting F for $n \cdot 100/D$ and w for $\sum R$.

The values of the divisor D and the factor F for different sizes of groups are given in Table II.

The standard error of the estimated c.v. can be derived without much difficulty, and may be stated as

$$\frac{V}{\sqrt{2N}} \sqrt{2n \left(\frac{\rho}{D}\right)^2 + \frac{2V^2}{10^4}} = \frac{V}{\sqrt{2N}} \sqrt{\alpha^2 + \frac{2V^2}{10^4}},$$

putting $\alpha = \sqrt{2n} \cdot \frac{\rho}{D}$, ρ being the standard deviation of the range, expressed in terms of standard deviation of the population [4, 7].

The values of ρ and α for different sizes of groups are given in Table III.

It may be seen from Table III that the size of group which reduces the error of estimation to a minimum is 8, since α has the lowest value for $n = 8$.

Thus, if easy means of obtaining w and W were available, the computation of c.v. would be very simple.

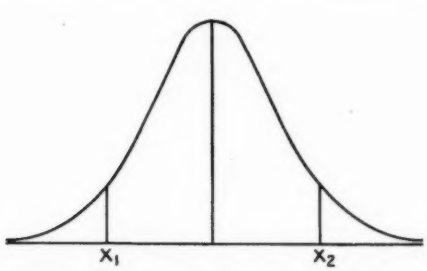

FIG. 2. *Curve of normal distribution.*

Probit Method

In the normal curve of distribution (Figure 2), if n_1 is the number of readings equal to or less than X_1, and n_2 is the number of readings equal to or greater than X_2, the probability of occurrence of a reading as small as or smaller than X_1 and that of a reading as large as or larger than X_2 may be given by $q_1 = n_1/N$ and $p_2 = n_2/N$, respectively. The estimate of c.v. may be obtained from the expression

$$V = 100 \cdot \frac{N}{W} \cdot \frac{X_2 - X_1}{\delta_1 + \delta_2},$$

where δ_1 and δ_2 are the values of the deviations (of X_1 and X_2 from the mean of the population), expressed in terms of the true standard deviation, corresponding to probabilities q_1 and p_2, respectively.* The values of δ_1 and δ_2 may be obtained by reference to the table of probits ([2], Table IX, pp. 38–40), which gives the value of the deviation, expressed in terms of standard deviation, corresponding to any probability q or p, expressed as a percentage. (If the table of probits is not available, refer to the table of the normal distribution ([2], Table I, p. 25).)

The standard error of the estimated c.v. can be obtained without much difficulty as follows: Let $(X_2 - X_1)$ be the estimated range corresponding to the probabilities p_2 and q_1. This range must obviously have an error of estimation. Its stand-

* A similar method requiring the use of probability graph paper was suggested by Spencer-Smith and Todd [5].

TABLE IV

Range	α
Interdecile 9–1	1.258
Interdecile 8–2	1.470
Interquartile	1.649
Interdecile 7–3	1.900
Interdecile 6–4	2.861

ard error [8] can easily be shown to be equal to

$$\frac{\sigma}{\sqrt{2N}}\sqrt{\frac{2p_1q_1}{y_1^2}+\frac{2p_2q_2}{y_2^2}-\frac{4p_2q_1}{y_1y_2}},$$

where σ is the true standard deviation of the population, and y_1 and y_2 are the values* of the ordinates of the normal curve of errors of unit area, corresponding to probabilities q_1 and p_2—*i.e.*, corresponding to deviations δ_1 and δ_2, respectively. Substituting the estimated value for σ, the standard error of $(X_2 - X_1)$ may be stated as

$$\frac{X_2-X_1}{\delta_1+\delta_2}\cdot\frac{1}{\sqrt{2N}}\sqrt{2\left[\left(\frac{q_1}{y_1^2}+\frac{p_2}{y_2^2}\right)-\left(\frac{q_1}{y_1}+\frac{p_2}{y_2}\right)^2\right]},$$

whence the standard error of V works out as

$$\frac{V}{\sqrt{2N}}\sqrt{\alpha^2+\frac{2V^2}{10^4}},$$

where

$$\alpha=\sqrt{2\left[\left(\frac{q_1}{y_1^2}+\frac{p_2}{y_2^2}\right)-\left(\frac{q_1}{y_1}+\frac{p_2}{y_2}\right)^2\right]}\Big/(\delta_1+\delta_2).$$

The values of α for different values of the X_2X_1 range are given in Table IV.

It may be seen from Table IV that the higher the range—*i.e.*, the lower the values of q_1 and p_2—the smaller the value of α, and hence the lower the error of the estimated c.v.

Thus, if easy means of knowing W (sum of the readings) and n_1 and n_2 corresponding to two suitable values of X (on either side of the mean) were available, the computation of c.v. would be very simple.

Comparison of the Efficiencies of the Different Methods

Let N_1, N_2, N_3, and N_4 be the numbers of variates that are required to be examined by the root-mean-square deviation, mean deviation, mean range, and probit methods, respectively, to get the estimates (of c.v.) of the same degree of accuracy, and in the mean range method let the variates be divided into groups of 8 and in the probit method the X_1X_2 range be so chosen as to make q_1 and p_2 both equal to 0.1—*i.e.*, the range chosen be the interdecile 9–1. If the values of c.v. obtained by the different methods are equally accurate, the precision of estimate must be the same in each case, and, hence, when the c.v. is ~30, one may write

$$\frac{1}{\sqrt{2N_1}}\sqrt{1+\frac{2\times30^2}{10^4}}=\frac{1}{\sqrt{2N_2}}\sqrt{1.068^2+\frac{2\times30^2}{10^4}}$$

$$=\frac{1}{\sqrt{2N_3}}\sqrt{1.158^2+\frac{2\times30^2}{10^4}}$$

$$=\frac{1}{\sqrt{2N_4}}\sqrt{1.258^2+\frac{2\times30^2}{10^4}},$$

which simplifies to

$$\frac{1.180}{N_1}=\frac{1.322}{N_2}=\frac{1.507}{N_3}=\frac{1.763}{N_4}.$$

If N_1 is 100, the values of N_2, N_3, and N_4 work out as 112, 128, and 149, respectively.

Thus, the examination of 100 variates by the root-mean-square deviation method is virtually the same as that of 112 variates by the mean deviation method, 128 variates by the mean range method, and 149 variates by the probit method.† The direct method appears, therefore, to be the most efficient, and of the three short-cut methods the mean deviation method has the highest and the probit method the lowest efficiency.

Practical Applications to the Determination of Irregularity of Yarns

The above principles may be usefully applied to the measurement of irregularity of yarns. In the case of jute yarns, which are generally very coarse, no practical difficulties arise, since the cuttings that are examined are usually of more than 1 in. in length* and can be weighed conveniently in a sensitive balance.

In the following methods, any sensitive chemical balance may be used, but a chainomatic balance of the Oertling type, reading up to 0.1 mg., is preferred.

Mean Deviation Method

The cuttings to be examined are all weighed together. Let the total weight be W. Then the

* These may be obtained by reference to the table of ordinates of the normal distribution ([2], Table II, p. 25).

* The practical aspects of measuring irregularity of jute yarns have been dealt with fully elsewhere [1].

mean weight* of a cutting is W/N. The chain of the balance is set at W/N, and the pieces which are lighter than W/N are sorted out and counted. Let the number be ν. No actual weighing is necessary during this sorting; the piece to be examined is placed on the left-hand pan, and if the pointer moves to the left the piece is lighter than the mean weight. The pieces which are palpably heavier or lighter can be sorted out by mere eye examination, and only the doubtful cases need be examined with the balance. All the light pieces thus sorted out are weighed together. Let the weight be ω. Hence, in the equation

$$V = 250.7\sqrt{N/(N-1)}\cdot\left(\frac{\nu}{N} - \frac{\omega}{W}\right),$$

all of the quantities on the right-hand side are known, and c.v. is obtained very easily. With a little practice, 20 to 25 min. would be sufficient for examining a set of 100 pieces, including calculation of c.v. The same determination would take about 3 hrs. if the direct weighing method (root-mean-square deviation) were employed.

Mean Range Method

The pieces are first weighed together to get W, and then arranged at random into a number of groups of equal size. The size of the group should preferably be 8, and in any case should not be less than 5 nor greater than 12. The heaviest and the lightest pieces in each group are sorted out by means of the balance. No actual weighing is necessary; in sorting out the heaviest piece, only three or four pieces which appear to the eye to be very thick need be examined. Two of them are placed on the two pans of the balance, and the one which is found to be lighter (if the pointer moves to the right, the piece on the right-hand pan is lighter) is replaced by another piece to be compared. Proceeding in this way, the heaviest piece can be sorted out. Similarly, in finding the lightest piece, only three or four palpably thin pieces need be examined. Two of the pieces are put on the two pans, and the one which is found to be heavier is replaced by another piece, and proceeding in this way the lightest piece is found. Thus, from each group, one heaviest piece and one lightest piece are obtained.

The heaviest pieces obtained from the m groups are put together on the left-hand pan and the lightest pieces on the right-hand pan. Weights are then added to the right-hand pan to secure balance. This weight is evidently equal to $\sum R = w$ in the expression used for estimating c.v.

Thus, in the equation $V = F\cdot\frac{w}{W}$, all of the quantities on the right-hand side are known, and c.v. is obtained very easily.

This method is as fast as the mean deviation method.

TABLE V

n	D	n	D
15	3.47	100	5.02
20	3.73	150	5.30
25	3.93	200	5.49
30	4.09	300	5.76
40	4.32	400	5.94
50	4.50	500	6.07
60	4.64	600	6.18
70	4.75	700	6.28
75	4.81	800	6.35
80	4.85	900	6.42
90	4.94	1000	6.48

Probit Method

The approximate standard deviation is first found from the extreme range. For this purpose, the pieces which appear to be the thickest and the thinnest are first sorted out by eye inspection. The difference in their weights gives the approximate extreme range, and this range divided by D gives the approximate standard deviation, s'. The values of D for higher sizes of population are given* in Table V, and those for smaller sizes in Table I.

The cuttings are then weighed together to get W. The chain of the balance is set at $(W/N) - s'$,† and all the pieces which are as light as or lighter than the chain weight are sorted out. Let the number of such pieces be n_1. Next the chain of the balance is set at $(W/N) + s'$,† and the pieces which are as heavy as or heavier than the chain weight are sorted out. Let the number of such pieces be n_2. Thus, $q_1 = n_1/N$ and $p_2 = n_2/N$.

* For a 10-lb. jute yarn the mean weight per inch is 8¾ mg.

* Taken from Tippett's original table [6].

† When the number of readings is sufficiently large, it is preferable to use the interdecile range 9–1 or a still higher range (see Table IV). But when the number of readings is small, a range greater than twice the standard deviation should not ordinarily be used, since the extreme portions of the distribution curve might be irregular, and its effect would be to introduce large uncertainty in the value of the estimated result.

If the deviations (expressed in terms of standard deviation) corresponding to the percentage probabilities of $100n_1/N$ and $100n_2/N$ are found from the table of probits ([2], Table IX, pp. 38–40) at δ_1 and δ_2, the estimate of c.v. may be given by

$$200 \cdot \frac{N}{W} \cdot \frac{s'}{\delta_1 + \delta_2},$$

since

$$(X_2 - X_1) = (W/N + s') - (W/N - s') = 2s'.$$

Since all of the quantities on the right-hand side of the above equation are known, c.v. is obtained easily.

This method is slower than the mean deviation and the mean range methods, since reference must be made to statistical tables for calculations of c.v. and its standard error.

Weight C.V. of Finer Yarns

These short-cut methods may also be applied to the determination of irregularity of wool and cotton yarns and other similar yarns. But with such finer yarns some practical difficulty arises—the cuttings being very light, it is difficult to weigh them in an ordinary balance. In order to obviate this difficulty, the cuttings may be weighed or compared, taking them in bundles. If the number of cuttings in a bundle is g, and if the c.v. of bundle weights is V_g, the estimate of weight c.v. of the yarn may be obtained from $\sqrt{g} \cdot V_g$.*

The number of cuttings in the bundles should be adjusted so as to make the bundles just as heavy as is convenient to compare or weigh them in a balance. It suffices if the average bundle weight is about 5 to 6 mg.

Any of the methods described above may be employed in estimating V_g. To get a reliable estimate of c.v., a sufficiently large number† of bundles must be examined. If the mean range method is employed, the total number of bundles should be divided preferably into groups of 8.

Mean Irregularity of a Bulk of Yarn Consisting of a Number of Bobbins, and the Method of Sampling

The Case of a Limited Number of Bobbins

The bulk of yarn of which the irregularity is to be measured usually consists of a number of cops, hanks, or bobbins. Although the yarn is spun from the same fiber to the same nominal grist,* it is found too often that the mean weight of a piece or the grist of the yarn varies significantly from bobbin to bobbin. The appearance of the cloth as well as the frequency of yarn breakage in weaving depends much more upon the short-distance variation in diameter or in weight per unit length of the yarn than upon the long-distance variation. Hence, in order to get a useful average measure of irregularity, the effect of variation of grist from bobbin to bobbin must be eliminated, since the superposition of this variation on the short-distance variation greatly increases the dispersion of the weight readings, and hence exaggerates the estimated coefficient of variation. In view of this, the following procedure is followed in estimating the mean irregularity in the case of a limited number of bobbins. The yarn is reeled off at a number of depths of each bobbin; preferably 8 (or 10) turns are reeled off at each of at least 15 (or 12) depths. These are placed side by side, and a short length (in the case of a 10-lb. jute yarn a 2-in. length is suitable) is cut off by means of a cutter having two sharp blades, the distance between which can be adjusted at will. Except in the case of the mean range method, the cuttings are all mixed up before examination. In the mean range method, the groups of cuttings (8 or 10 in each) are examined separately.

Let the number of bobbins to be examined be k. The cuttings from each bobbin are examined separately. Let the standard deviations and means for the k bobbins be σ_1, M_1; σ_2, M_2; σ_3, M_3; $\cdots \sigma_k$, M_k. The pooled standard deviation for the k bobbins is given by $\sqrt{\sum \sigma^2/k}$, and the average weight of a cutting by $\sum M/k$. Therefore, the

* If σ_g is the standard deviation of the bundle weights, the estimate of standard deviation, σ, of the cutting weights may be given by $\frac{\sigma_g}{g} \cdot \sqrt{g}$, or $\frac{\sigma_g}{\sqrt{g}}$. Hence, if M is the mean cutting weight,

$$V_g = \frac{\sigma_g}{Mg} \cdot 100 = \frac{\sigma}{M} \cdot 100 \cdot \frac{1}{\sqrt{g}} = \frac{V}{\sqrt{g}},$$

or

$$V = \sqrt{g} \cdot V_g.$$

† A similar method was recently suggested by Martindale [3]. The precision of estimation with this method does not, however, appear to be as high as is supposed by the author, and 100 bundles are too few for an accurate estimation of c.v. This has been discussed more fully elsewhere [1].

* Grist gives a relative measure of the coarseness of the yarn, and is measured in pounds per spyndle, a spyndle being 14,400 yds.

mean irregularity, V_m, can be stated as

$$V_m = \frac{\sqrt{\sum\sigma^2/k}}{\sum M/k} \cdot 100 = 100\sqrt{k} \cdot \sqrt{\sum\sigma^2}/\sum M.$$

Hence, if $s_1, s_2, s_3, \cdots s_k$ are the estimated standard deviations, and W_1/N, W_2/N, $W_3/N, \cdots W_k/N$ the observed means, the estimate of mean weight c.v. would be given by

$$V_m = \frac{100\sqrt{k} \cdot N\sqrt{\sum s^2}}{\sum W}.$$

The equation takes the following final forms when different short-cut methods are employed:

Mean deviation method:

$$V_m = \frac{250.7\sqrt{k}}{\sqrt{N(N-1)}} \frac{\sqrt{\sum(\nu W - N\omega)^2}}{\sum W}.$$

Mean range method:

$$V_m = \frac{F\sqrt{k} \cdot \sqrt{\sum w^2}}{\sum W}.$$

Probit method:

$$V_m = \frac{200 \cdot N\sqrt{k}}{\sum W} \sqrt{\sum \left(\frac{s'}{\delta_1 + \delta_2}\right)^2}.$$

The standard error of V_m may be stated in a general way as

$$\frac{V_m}{\sqrt{2Nk}} \sqrt{\frac{k\sum(\alpha^2\sigma^4)}{(\sum\sigma^2)^2} + \frac{2V_m^2}{10^4}},$$

where α has the same significance as before, its value depending upon the particulars of the method employed in determining the individual standard deviations. In actual calculation of standard error, however, $\frac{\sum(\alpha^2 s^4)}{(\sum s^2)^2}$ may be substituted for $\frac{\sum(\alpha^2\sigma^4)}{(\sum\sigma^2)^2}$, which would work out as $\frac{\alpha^2\sum(\nu W - N\omega)^4}{[\sum(\nu W - N\omega)^2]^2}$ in the mean deviation method and as $\frac{\alpha^2\sum w^4}{(\sum w^2)^2}$ in the mean range method.

In obtaining estimates of individual standard deviations and means, at least 120 pieces should be examined from each bobbin.

When the sample is large—say, 120 pieces or more for each bobbin—and the number of bobbins is more than 10, each of the short-cut methods outlined here would unquestionably give results closely in agreement with that obtained by the root-mean-square deviation method. But even when the sample is not sufficiently large, the difference between the result obtained by the root-mean-square deviation method and by the other methods would not be significant in most cases.

TABLE VI

Weight c.v. results and their standard errors

Bobbin No.	Root-mean-square deviation	Mean deviation	Mean range	Probit
1	40.5±4.26	42.3±4.73	34.8±4.00	40.3±5.81
2	36.2±3.71	38.1±4.16	37.9±4.41	43.0±6.26
3	36.4±3.74	33.0±3.51	36.4±4.21	30.7±4.03
4	32.0±3.21	33.7±3.60	33.9±3.88	32.0±4.27
5	26.2±2.55	28.0±2.91	28.2±3.15	27.3±3.31
6	35.2±3.59	35.2±3.79	36.1±4.17	34.9±4.57
7	38.0±3.94	32.8±3.49	38.5±4.50	27.6±3.55
8	37.6±3.89	34.5±3.70	33.9±3.88	32.9±4.26
9	37.8±3.91	35.3±3.80	39.0±4.57	29.0±3.68
10	30.1±3.23	30.7±3.23	28.7±3.21	31.8±4.14
Mean c.v.*	35.4±1.18	34.6±1.21	35.1±1.31	33.1±1.16

* In calculating the standard error of the mean c.v., the value of α was taken as 1, 1.068, and 1.158 in the first, second, and third methods, respectively. In the fourth method the value of α had to be calculated for each bobbin separately; the average value of α for the 10 bobbins was 1.370, the individual values ranging from 1.269 to 1.473 (see Table VII).

Experimental Results

The results of an actual experiment with a 10-lb. jute yarn are given in Table VI, the complete data being given in Table VII. The bulk consisted of 10 bobbins; only sixty 2-in. pieces were examined from each bobbin. In the mean range method, the cuttings were examined in groups of ten.* The approximate over-all mean and standard deviation for the ten bobbins were roughly found† by preliminary examination at 14.5 mg. and 5 mg., respectively, and hence in the probit method the chain of the balance was set in turn at $W/N - s' = 14.5 - 5 = 9.5$ mg. and $W/N + s' = 14.5 + 5 = 19.5$ mg. The same pieces were examined by each method.

Discussion of Results

It may be seen that there is no significant difference between any two of the mean weight c.v. results. It is also interesting that even among the

* Sixty cuttings cannot be divided into groups of 8, and the best group size with them is 10 (see Table III).

† For greater accuracy this should be done for each bobbin separately. In the present test experiments the number of cuttings examined from each bobbin was only 60, and it was not worth while to do this.

TABLE VII

Bobbin No.	Root-mean-square deviation method			Mean deviation method			Mean range method	
	W (mg.)	$\Sigma(X-\bar{X})^2$	s^* (mg.)	ν	ω (mg.)	$s\dagger$ (mg.)	w (mg.)	$s\ddagger$ (mg.)
1	878	2075.6500	5.931	36	380	6.185	94	5.091
2	824	1459.5833	4.974	33	329	5.233	96	5.199
3	786	1342.8125	4.771	36	369	4.323	88	4.766
4	950	1516.9000	5.071	32	380	5.336	99	5.361
5	887	884.2125	3.871	31	360	4.141	77	4.170
6	820	1362.8500	4.806	35	364	4.817	91	4.928
7	928	2036.1093	5.875	35	421	5.070	110	5.957
8	881	1798.9333	5.522	37	423	5.067	92	4.982
9	958	2152.1500	6.040	36	441	5.637	115	6.228
10	805	964.2458	4.043	33	345	4.118	71	3.845

* $s = 0.13019\sqrt{\Sigma(X-\bar{X})^2}$.
† $s = 0.00070216\ (\nu W - 60\omega)$.
‡ $s = 0.054156w$.

individual weight c.v. results for different bobbins, there is no significant difference between any two corresponding results.

It has been shown (p. 102) that of the three short-cut methods, the mean deviation method is superior to the others, as far as the accuracy of estimation is concerned. But this is true only when the distribution is truly normal. In practice, the distribution is rarely truly normal, and the precision of the mean deviation method as well as of the probit method might be affected if the distribution deviates much from the truly normal type or is appreciably skewed, whereas the precision of the mean range method would not likely be so much affected, since the variates are divided into a number of small groups which are examined separately and the observed ranges are averaged to obtain the standard deviation. This might be the reason why in Table VI the difference between the mean results as obtained by the first and second methods is found to be more than that between the results obtained by the first and third methods. When the nature of distribution is not definitely known, it may be less risky, therefore, to use the mean range method. From the expression of standard error of weight c.v., the probit method as described here appears to be rather less accurate than the other methods. Moreover, the calculation of the standard error of the mean result is somewhat complicated, because the value of α must be found for each bobbin separately. But this as well as the mean deviation method may be preferred to the root-mean-square deviation method when the object is to get an idea of the frequency of yarn breakage in weaving, which is virtually the same as the number of cutting weights falling below a certain value. When the object, however, is to get an idea of the unevenness of the cloth, the mean range method is preferred.

The Case of a Large Number of Bobbins

When the bulk of yarn consists of a very large number of bobbins, the method of estimating mean weight c.v. must be modified. It is not practicable to examine all the bobbins, and, hence, out of the whole lot, only a small number of bobbins are selected at random for examination. Let the number of bobbins be k (should be 20 or more) and their estimated weight c.v.'s V_1, V_2, V_3, $\cdots V_k$.* These estimates of c.v. may be regarded as a set of independent variates drawn from a large population of V's, and hence the mean weight c.v. and its standard error will be given by $\sum V/k$ and $\sqrt{\sum(V-\bar{V})^2/k(k-1)}$, respectively.

The following values of mean weight c.v. and standard error work out from the data given in Table VI (considering the 10 results as a set of independent variates).

Method	Mean weight c.v.
Root-mean-square deviation	35.0 ± 1.37
Mean deviation	34.4 ± 1.23
Mean range	34.7 ± 1.19
Probit	33.0 ± 1.64

* A sufficient number of cuttings should be examined in order to make the estimates fairly precise.

TABLE VII—*Continued*

Probit method

X_1 (mg.)	X_2 (mg.)	X_2-X_1 (mg.)	n_1	n_2	q_1	p_2	δ_1	δ_2	$(\delta_1+\delta_2)$	s^{**} (mg.)	y_1	y_2	α
9.5	19.5	10	14	10	0.2333	0.1666	0.7279	0.9674	1.6953	5.899	0.3061	0.2498	1.473
9.5	19.5	10	14	10	0.2333	0.1666	0.7279	0.9674	1.6953	5.899	0.3061	0.2498	1.473
9.5	19.5	10	12	3	0.2000	0.0500	0.8416	1.6449	2.4865	4.022	0.2799	0.1032	1.371
9.5	19.5	10	7	13	0.1166	0.2166	1.1918	0.7835	1.9753	5.063	0.1961	0.2935	1.390
9.5	19.5	10	6	7	0.1000	0.1166	1.2816	1.1918	2.4734	4.043	0.1754	0.1961	1.269
9.5	19.5	10	11	7	0.1833	0.1166	0.9027	1.1918	2.0945	4.774	0.2655	0.1961	1.347
9.5	19.5	10	4	12	0.0666	0.2000	1.5011	0.8416	2.3427	4.269	0.1293	0.2799	1.354
9.5	19.5	10	9	9	0.1500	0.1500	1.0364	1.0364	2.0728	4.824	0.2332	0.2332	1.341
9.5	19.5	10	7	10	0.1166	0.1666	1.1918	0.9674	2.1592	4.631	0.1961	0.2498	1.328
9.5	19.5	10	12	4	0.2000	0.0666	0.8416	1.5011	2.3427	4.269	0.2799	0.1293	1.354

** $s = (X_2 - X_1)/(\delta_1 + \delta_2)$.

Estimation of Mean Irregularity in the Case of Fine Yarns

The procedure in this case is practically the same as described above. The only change necessary is that instead of examining 120 cuttings or so, 120 bundles, each containing a suitable number of cuttings (say, g), should be examined for each cop (or bobbin). Treating each bundle as a single composite cutting, the mean c.v. (of bundle weights) and its standard error may be obtained as before. The values thus obtained when multiplied by $\sqrt{g}$ give the required results for the mean irregularity (weight c.v.) of the yarn and its standard error.

Summary

Some easy and quick methods for finding mean deviation, mean range, and probit and their applications to the estimation of the weight irregularity of yarns are described. Experimental observations confirm that all these methods are capable of giving results closely in agreement with those obtained by the root-mean-square deviation method. When the distribution is truly normal, the mean deviation method proves to be superior to the mean range method, but when the distribution deviates from the truly normal type or is asymmetrical, the mean range method is likely to agree more closely with the root-mean-square deviation method. The probit method as described is not so accurate as the mean deviation or the mean range method. It is concluded that when the object is to get an idea of the frequency with which yarn breakages may occur in weaving or winding, from the estimated value of irregularity, the mean deviation or the probit method are preferred to the mean range method, but when the object is to get an idea of the unevenness of the woven fabric, the mean range method is preferred. The method of estimating mean irregularity of a bulk of yarn consisting of a number of bobbins is discussed. It is found that the short-cut methods outlined are about five times as quick as the direct root-mean-square deviation method.

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The Nature of a Fabric Surface: Thickness-Pressure Relationships*

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A STUDY of fabrics made of synthetic fibers and of blends of various synthetics with wool is now in progress in these laboratories. Work on some phases of this program has reaffirmed the importance of the surface character in the tactile impressions of a fabric as well as in many aspects of service behavior. The surface fuzz, furthermore, may contribute substantially to the over-all thickness of a fabric, and thus plays a part in functional properties, such as warmth [2, 4]. For these reasons, attention was directed to the determination of the thickness of fabrics at various pressures and to the definition of the thickness-pressure function over a fairly wide range of pressures. Such a functional relationship would be useful in representing the whole thickness-pressure curve quickly by means of the constants of the equation, and, if the form of the equation were chosen appropriately, the constants might be expected to be descriptive of the "character" of the cloth—the fibers composing its surface and particulars of its construction.

General Thickness-Pressure Relationship

Considerable work has been reported on the compressibility of wool in bulk (see, for example, van Wyk [5]) in relation to the subjective evaluation of handle. In a similar connection, Hoffman and Beste [1] suggested an exponential thickness-pressure function for fabrics.

In the course of the present investigation, the possibility of expressing the relationship between thickness, t, and pressure, p, as a hyperbolic function was considered. Examination of a typical t-p curve suggests the form

$$t = a + b/(p + c), \qquad (1)$$

in which a, b, and c are constants.

A graph of this function, shown in Figure 1, illustrates geometrically the meaning of the constants. The constant a corresponds to the thickness at high pressures—that is, when the fraction $b/(p + c)$ becomes vanishingly small. For a fabric, therefore, a is the limiting thickness of the compressed fabric and fuzz as the pressure increases. As the pressure approaches zero, the thickness is given by $(a + b/c)$, and hence b/c represents the total compression possible. If equation (1) is rearranged algebraically to give

$$(p + c)\ (t - a) = b, \qquad (2)$$

a number of additional points of interest may be clarified.

Equation (2) is in the same form as the van der Waals' equation relating the pressure and volume of a gas. In brief, the van der Waals' equation of state applies corrections to the pressure and to the volume of an ideal gas to account for the attractive forces between the molecules and for the volume actually occupied by the molecules, respectively. The analogy to the fabric case is quite interesting. The constant a in equation (2) may be considered as a "correction" to the thickness or volume of the fabric which corrects the observed thickness at any pressure for the space occupied by compressed yarns and surface

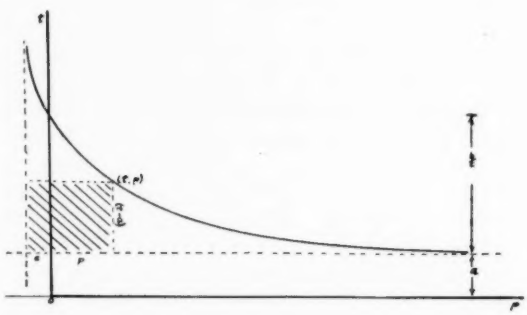

FIG. 1. *The thickness-pressure relationship for a fabric:* $t = a + \frac{b}{(p + c)}$.

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fibers. The constant c is a correction to the pressure, which accounts for the fact that the fabric does not become thicker without limit as the pressure decreases; the constant c may be thought of as a force of attraction between the fibers and between yarns which holds them together when there is no external pressure on the cloth.

In the case of a gas, the product of the pressure and the volume is proportional to the energy content. The constant b in equation (2) is also equivalent to an energy or work, and corresponds geometrically to an area under the thickness-pressure curve (shaded area in Figure 1).

Experimental Results

The suitability of the proposed equations for representing the thickness-pressure function was tested, using a variety of materials of differing construction and fiber type. Thickness measurements were made with the Schiefer compressometer [3] over a range of pressure of 0.002–2.0 lbs./in.^{2} The pressure stations were 0.002, .004, .007, .01, .02, .04, .07, and 0.1 lb./in.^{2} using a presser foot 5 in. in diameter, and 0.1, .2, .35, .5, .75, 1.0, 1.5, and 2.0 lbs./in.^{2} using a presser foot 1 in. in diameter. The general procedure was to make the measurements with the 5-in. foot stepwise at the pressure levels noted above, followed by stepwise unloading; measurements were then made in a similar way with the 1-in. foot using another specimen of material or with the same specimen after relaxation.

TABLE I. TYPICAL VALUES FOR THE "CONSTANT" b, CALCULATED AS DESCRIBED IN THE TEXT, FOR VARIOUS FABRICS (LOADING CYCLE)

	Calculated values of b			
Pressure (lb./in.^{2})	Wool serge (lb./in.)	Wool blanket (lb./in.)	Orlon sateen (lb./in.)	Cotton flannel (lb./in.)
0.002	4.06×10^{-3}	13.3×10^{-3}	0.64×10^{-3}	1.92×10^{-3}
.004	3.84	12.6	.57	1.73
.007	3.54	12.1	.53	1.60
.01	3.42	11.7	.45	1.56
.02	3.36	—	.48	1.54
.04	3.42	12.9	.49	1.63
.07	3.85	—	.52	1.92
Mean	3.64	12.5	.53	1.70
.1	3.75	15.9	.53	1.95
.2	4.25	17.3	.65	2.25
.35	4.80	—	.76	2.80
.5	4.95	—	.83	2.75
.75	4.80	—	.88	2.40
1.0	4.20	20.0	.73	2.10

Upon fitting the experimentally observed data to equations (1) or (2), it was found that for fabrics, a, b, and c were actually not constant for measurements over any appreciable range in pressure, and appeared to be interdependent. This might have been expected in view of the likelihood that several different mechanisms operate at various stages during the compression of a fabric—*viz.*, the collapsing of fibers normal to the surface as columns, the bending of surface fibers as beam elements, the bending of fiber segments in the yarn against the resistance due to crimp and interfiber friction. Nonetheless, several empirical methods for defining a value for these "constants" were found which permitted the calculation of the thickness at any pressure (in the range 0.002–2.0 lbs./in.^{2}) with satisfactory precision. One of the simplest of these procedures which appeared to be suitable for a wide variety of fabric types was as follows:

(1) The value of a was defined as the thickness in mils observed at a pressure of 2.0 lbs./in.^{2}, which was the highest pressure readily achieved with the instrument used. It was recognized that further decrease in thickness would occur at higher pressures, but the extent of this additional compression is very small for most fabrics. It is conceivable, however, that in special cases the thickness at some higher pressure may be more appropriate for defining a.

(2) The value of c was assumed to be 0.05 lb./in.^{2} in every case; this is approximately in the middle of the range of the values for a number of fabrics found by substitution in equation (1) at the lower pressures.

(3) With a and c defined as above, b was calculated by equation (2) as the product of $(p + c) \times (t - a)$ at every station for which observations were made. Typical results for the loading cycle of a number of fabrics are shown in Table I. The value of b for a fabric was defined as the mean for all points measured at less than 0.1 lb./in.^{2} It should be observed that due to the form of equation (1), as the pressure increases, the fraction $b/(p + c)$ contributes less and less to the estimate of the thickness. It is therefore possible to use the value of b obtained from the low pressure region in estimating the thickness over the whole pressure range with little effect on the accuracy of the estimate.

TABLE II. COMPARISON OF OBSERVED AND CALCULATED THICKNESS

No.	Fabric type	Fiber content	Calculation constants			0.004 lb./in.²			
				Loading	Recovery	Loading		Recovery	
			a (mils)	b (lb./in.)	b (lb./in.)	obs.	calc.	obs.	calc.
A	Serge	Wool	34	1.94×10^{-3}	1.52×10^{-3}	72	70	65	62
13	Serge	Wool	42	3.64	2.95	113	109	98	97
N2	Serge	Nylon	35	1.35	0.93	62	60	53	52
54047	Blended serge	70 Wool/30 Dynel	31	1.32	1.01	60	56	51	50
HB	Blanket	Shrink-resistant wool	82	12.5	10.2	315	313	267	271
25	Blended covert	40 Wool/50 viscose/ 10 nylon	49	3.81	2.99	119	120	100	102
CF	Flannel	Cotton	25	1.70	1.37	57	57	49	50
J3	Blended jersey	60 Wool/40 Vicara	25	1.36	1.15	52	50	46	46
SLT	Twill lining	Staple viscose	16.7	0.69	0.43	33	30	26	25
FLT	Twill lining	Filament viscose	16.6	0.17	0.16	19.5	19.5	19	19.5
45	Sateen	Orlon	29	0.53	0.41	39.5	39	37	36.5
RV	Velveteen	Viscose cut pile	52	0.86	0.66	69	68	64	64
TA	Tropical suiting	50 Viscose/50 acetate	18	0.48	—	27.5	27	—	—
TB	Tropical suiting	Wool	21	0.73	—	36	34.5	—	—
RS	Rubber sheeting	Rubber	34.6	0.19	0.17	38	38	37.5	37.5

The increase in the magnitude of b at higher pressures, shown in Table I, is noteworthy. It suggests a gross change in the type of fabric elements which oppose compression. Hoffman and Beste [1] observed an analogous effect, and proposed the reasonable hypothesis that the compression process changes as the pressure increases from one involving the superficial hairs to one involving bulk fabric. In the work described below, the mean values of b at the lower pressures, as defined above, are used for making comparisons since for many purposes the low pressure region of the thickness-pressure relationship is of most interest. The constants a, b, and c will henceforth be understood as defined in the manner described unless otherwise stated.

In view of the arbitrariness of the procedure employed for defining the constants of the equation, data are presented in some detail comparing some of the observed values of thickness at various pressures with those calculated from the equations. The results for a wide variety of fabric types made of various fibers are given in Table II. The agreement between the calculated and observed thicknesses is quite good for the many types of materials tested, and hence it is believed that the compression behavior of a fabric may be represented satisfactorily by the two values a and b; the thickness at any pressure in the range 0.002 to 2.0 lbs./in.² estimated by substituting the "constants" in the equation agrees with the observed values generally to within 10% or better.

The Nature of the Fabric Surface

The discussion of equations (1) and (2) indicated that b has the dimensions of work or energy. It was considered of interest to inquire whether this parameter (determined at low pressures) would of itself be of use in characterizing fabrics with respect to a group of related textile properties included in the terms "hairiness," "fuzziness," "loft," and "compressibility." It should be noted that the compressibility may be strictly defined in terms of equation (1) as:

$$dt/dp = -b/(p+c)^2, \qquad (3)$$

which reduces at low pressures to $(-b/c^2)$.

Examination of the values of b for the various fabric types in Table II suggests that b is indeed descriptive of the surface character of the materials studied. Thus, the first three samples in Table II were similar with respect to particulars of construction. Sample A is a harder finished wool serge than sample 13; these differences in the nature of the surface fuzziness are readily appreciated from photographs made of the folded edges of these two samples (shown in Figure 2). The nylon serge, sample N2, is even smoother than sample A. The blanket, sample HB, has a long brushed nap, and this is reflected in the very high value for b. Very smooth, nonhairy fabrics yield low values for b, as represented in Table II by the rayon lining (sample FLT), the Orlon sateen (sample 45), the blended tropical (sample TA), and the rubber

AT VARIOUS PRESSURES DURING LOADING AND UNLOADING CYCLE

Thickness (mils) at pressure of:															
0.01 lb./in.²				0.04 lb./in.²				0.1 lb./in.²				1.0 lb./in.²			
Loading		Recovery		Loading		Recovery		Loading		Recovery		Loading		Recovery	
obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
65	66	58	59	54	56	49	51	47	47	43	44	36	36	35	35
99	103	87	91	80	83	74	75	67	66	60	62	46	46	44	45
56	57	49	50	48	50	43	45	43	44	38	41	37	36	36	36
52	53	47	48	43	46	41	42	39	40	36	38	32	32	32	32
279	291	244	253	226	221	208	195	188	166	—	—	101	94	91	92
109	113	97	99	92	91	86	82	79	74	64	69	55	53	51	52
51	53	46	48	43	44	41	40	38	36	32	34	27	27	25	26
46	48	43	44	39	40	38	38	36	34	33	33	27	26	26	26
28	28	24	24	22	24	20	22	19	21	—	—	17	17	17	17
19	19.5	19	19.5	18.5	18.5	18.5	18.5	18	17.5	—	—	17.5	17	16.5	17
37.5	38	35.5	36	34.5	35	33	33.5	32.5	32.5	31	31.5	29.5	29.5	29	29.5
66	66	62	63	61	62	59	59	60	58	59	56	55	53	54	53
25.5	26	—	—	22.5	23	—	—	20.5	21	—	—	18.5	18.5	—	—
32	33	—	—	28	29	—	—	26	26	—	—	22	22	—	—
37	37.5	37	37	36	36.5	36	36	35.5	35.5	35	35.5	34.5	34.5	35	34.5

sheeting (sample RS). An interesting comparison may be made between the values for b for rayon twill lining samples SLT and FLT, the values indicating the increase in hairiness resulting from the use of staple fiber in sample SLT, as contrasted with the filament fabric, FLT. The surface of all-wool tropical TB is also fuzzier than the acetate-viscose suiting, TA, as indicated by the values for b, and this result is in agreement with visual and tactile impressions of the fabrics. The results obtained for sample RV, the rayon velveteen, are of interest. It might be supposed that such a fabric would be hairy and hence yield a large value for b. Actually, this fabric presents a uniform surface to the fingers as a consequence of the uniform and short pile height and of the high density of the pile. The low value for b is therefore in accordance with the nonhairy sensation given by compression of this fabric with the fingers.

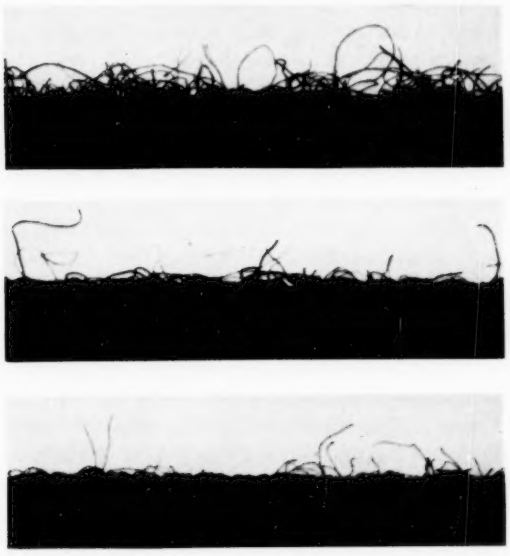

FIG. 2. *Photographs of folded edges of fabrics, magnified 7 ×.* Top—*sample 13, hairy wool serge.* Middle—*sample A, smoother wool serge.* Bottom—*sample N2, smoothest nylon serge.*

It can be observed from the data in Table II that the values for b are lower for the recovery cycle than for the loading cycle. This is consistent with the hysteresis effect in compression, whereby less work is recovered during unloading than is required to compress the fabric. The ratio of the values of b obtained from the recovery and from the loading cycles may therefore be considered as a measure of the resilience or the recoverability from compression.

The results presented show that differences in fabric hairiness are reflected in differences in the parameter b obtained from thickness-pressure data. This attribute of a fabric is one of the factors involved in subjective judgments of handle. Additional tests were made, therefore, to determine whether small differences in fuzziness could be detected subjectively, and whether changes in manufacturing

TABLE III. SUBJECTIVE EVALUATION OF SMOOTHNESS OR HAIRINESS OF FABRICS

Smooth											Hairy
	FLT	TD	TA								
	FLT	TA	TD								
	FLT	TD*	TA*								
	FLT	TD	TA								
			TA	TE	TB						
			TA	TE	TB						
			TA	TE	TB						
			TB	TA	TE						
					TB	54047	CF				
					TB	54047	CF				
					TB	54047	CF				
					TB	54047	CF				
							A	CF			
							CF	A			
							CF	A			
							CF	A			
								A	13		
								A	13		
								13	A		
								A	13		
									13	25	HB
									13	25	HB
									13	25	HB
									13	25	HB
average fabric type	FLT Viscose lining	TD Tropical suiting	TA Tropical suiting	TE Tropical suiting	TB Tropical suiting	54047 Blended serge	CF Cotton flannel	A Wool serge	13 Wool serge	25 Blended covert	HB Wool blanket
b value	0.17×10^{-3}	.37	.48	.57	.73	1.32	1.70	1.94	3.64	3.81	12.5

* These samples could not be differentiated by this observer.

procedure or finishing operations expected to modify the surface would affect the magnitude of b.

A series of eleven samples covering a wide range of b values was selected for subjective evaluation. These were arranged in overlapping groups of three or two in order corresponding to the b values. Four different observers were asked to rank the samples in each group on a scale of smoothness to hairiness. It was found that when the number of specimens offered to the panel at any one time was kept small and and if the offerings were spaced at intervals of not less than an hour, the observers were able to make decisions quite readily and consistently and in surprisingly good agreement with each other. The data summarizing results of subjective judgments of hairiness are given in Table III; for convenience, the b values (loading cycle) are also tabulated. Samples appearing in the same horizontal line were offered for judgment at the same time to one observer.

The samples are seen to be ranked subjectively by the observers on the average in the same order as the b values obtained from compression measurements. This relationship appears to hold for fabrics differing widely with respect to this type of handle. For practical purposes it may be more important to be able to differentiate among fabrics of similar type. Thus, a manufacturer or buyer would ordinarily wish to make a selection among a group of similar fabrics—*e.g.*, tropical suitings or serges. From the results in Table III, it appears to be possible to use the b values for this purpose as well, since in comparisons among the more homogeneous types—tropical suitings (samples TD, TA, TE, and TB) and serges (samples 54047, A, and 13)—the b values discriminate among the samples in the same sense as the subjective judgments.

Since b appears to be a sensitive index of the fuzziness of fabrics, certain types of finishing operations should be expected to influence this parameter. Examples of the results obtained from compression measurements of fabrics subjected to napping or shearing are given in Table IV. In addition, other effects produced by the use of coarser fibers in a blend and by variations in yarn twist are tabulated here.

The data indicate that the value of b calculated from the thickness-pressure data is in accord with the changes produced in the surface by napping or by shearing. The calculated value of b therefore ap-

TABLE IV. THE EFFECT ON b VALUES OF FINISHING OR MANUFACTURING OPERATIONS

No.	Fabric type	Manufacturing or finishing variable	Value of b from compression data (lb./in.)
HB	Wool blanket	before shearing	12.5×10^{-3}
	Wool blanket	after shearing	8.68
13	Wool serge	before shearing	3.64
	Wool serge	after shearing	1.97
54047	Dynel/wool serge	before napping	1.32
20	Dynel/wool serge	after napping	2.03
N2	Nylon serge	before napping	1.35
	Nylon serge	after napping	2.80
J3	Vicara/wool jersey	3-den. Vicara	1.36
J7	Vicara/wool jersey	7-den. Vicara	2.61
I	Plain woven wool fabric	6 t.p.i. (in singles)	2.52
J	Plain woven wool fabric	15 t.p.i. (in singles)	1.94

pears to respond to the height of the fuzz fibers and to the number of such fibers present. This probably also explains the results with samples I and J in Table IV; these fabrics are identical except for the singles twist of the 2-ply filling yarns. The higher twist factor in sample J results in a harder fabric, with the fiber ends more effectively bound in, and the resulting b value reflects this.

The comparison between samples J3 and J7, the blended jerseys, is of interest; these fabrics are identical except for the denier of the Vicara component (40%) of the blend. The coarser fibers are not held in the yarn structure as easily as are the finer 3-denier fibers, and the latter are more easily deformed during compression. The values of b shown in Table IV are indicative of this difference in the fabrics, and are in agreement with visual and tactile judgments. Results comparing a staple with an otherwise identical filament fabric (samples SLT and FLT, Table II) have already been discussed.

In general, it is concluded that a parameter, b, may be calculated from thickness-pressure measurements which is characteristic of the hairiness of a fabric. The magnitude of b appears to be related to the height and density of the surface fibers and to their stiffness.

Since fabrics in use are employed as multilayer assemblies, it was considered of interest to determine whether the characteristic values of b were additive in nature. Some data on this point are shown in

TABLE V. VALUES OF b FOR MULTILAYER ASSEMBLIES

No.	Arrangement of fabrics	b (lb./in.)
13	pressed wool serge—1 layer	0.80×10^{-3}
	2 layers	1.93
	3 layers	2.75
N2	pressed nylon serge—1 layer	0.42
	3 layers	1.19
13+N2	1 layer each wool and nylon serge	1.32
U	wool/cotton underwear	2.31
13+U	wool serge over underwear	2.99

Table V. These results demonstrate that this parameter is approximately additive, the b values calculated from layered assemblies agreeing surprisingly well with those estimated by summation of the individual values. It is interesting that, on the average, a panel rated 3 layers of fabric as being fuzzier (on a smoothness to fuzziness scale) than 2 layers of the same fabric. Thus, while the surface hairiness of the fabrics in these cases are identical, it appears that the tactual sensation perceived is influenced by the compressibility of the assembly. It should be noted that the compressibility is also directly related to the magnitude of b, as suggested by equation (3).

Summary

1. An equation, $t = a + b/(p + c)$, analagous to the van der Waals' equation of state, has been proposed for describing the relationship between thickness, t, and pressure, p, for fabrics. While the parameters a, b, and c are not constant over a wide range of pressures, they may be defined simply for each fabric in an empirical manner, as described in the text, and the equation may then be used to estimate the thickness at any pressure in the range from 0.002 to 2.0 lbs./in.^{2}, in good agreement with the observed values.

2. The magnitude of b appears to relate to the surface character of a wide variety of fabrics. The value of b is increased by napping and decreased by shearing. The use of staple fibers in place of filament, of low-twist in place of high-twist yarns, and of large denier in place of fine fibers in otherwise comparable fabrics is shown to result in increased values for b. In general, therefore, b appears to vary directly with the height and density of the surface fibers and inversely with their stiffness.

3. The value of b calculated from compression data correlates satisfactorily with subjective evaluations of surface fuzziness in a group of fabrics that are quite similar in type.

4. The value of b obtained from measurements of layered assemblies is similar to that obtained from a summation of the b values of the individual components. This result may be a consequence of the relationship between b and the compressibility.

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The Felting in Laundering of Wool Blends*

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THE INTRODUCTION of many new fibers in recent years has stimulated widespread interest in blends and in research on the effect of blending on fabric properties and processing. For example, it is well known that the addition of a non-wool component affects the felting behavior of wool fabrics, especially with respect to the fulling process, and Whewell and coworkers [14, 15, 16] have made important studies in this field. While the behavior of blended fabrics in laundering might be expected to follow similar patterns, it was considered of interest to investigate the consequences of the blending of various fibers with wool on the shrinkage of the resulting fabrics in laundering. It is the purpose of this paper to describe such studies, which were part of an investigation of shrink-resistant treatments and the shrinkage behavior of wool undertaken for the Office of The Quartermaster General.

Materials and Methods

The fibers used were as follows: wool, 60's grade; viscose, 2½-in. staple, 3 denier; nylon, 3½-in. staple, 3 denier; Vicara, 4-in. staple, 3 denier.

Blends were made by gilling the slivers in an intersecting gill box, using at least 4 passes per blend. The nominal proportions sought were 75%, 50%, 25%, and 10% of the non-wool component in each case. The resulting blends were sampled at several places along the final sliver, and analyses were made in the appropriate case for nylon or for viscose by solution in 70% H_2SO_4 [1]. The wool content of Vicara blends was estimated by solution in 5% KOH at the boil and correcting for the small amount of Vicara dissolved by this procedure by running an all-Vicara control simultaneously.

The blended slivers were spun into yarns—1/8 worsted, 5 t.p.i.—and these were knitted into tubing using a plain flat stitch; after relaxation the construction in all cases was 12–13 wales and 15–16 courses per inch.

The knitted tubings were relaxed in water at 100°F for 2 hrs. and air-dried. The laundering procedure consisted of washing in a 27-in. rotating washwheel at 100°F with low-titer soap as detergent at a 10-in. water level for 30 min., followed by two 2-min. rinses.

Since the blends were also available in sliver form, the felting behavior was studied by means of the top shrinkage test [3]. Top shrinkage has been shown to be related to the laundering behavior of shrink-resistant wool.

* This work constitutes a part of the Army Quartermaster program on the shrink-resistance of wool for military clothing, which is under the supervision of the National Research Council Committee on Textile Finishing Research.

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TABLE I. FELTING SHRINKAGE OF BLENDED KNIT FABRIC IN LAUNDERING

Fiber composition		Felting shrinkage	
Wool (%)	Other (%)	Length (%)	Width (%)
100	—	22	22
89	11, viscose	25	22
78	22, viscose	29	29
50	50, viscose	32	28
26	74, viscose	38	35
91	9, Vicara	23	25
73	27, Vicara	24	30
52	48, Vicara	22	30
22	78, Vicara	6	22
88	12, nylon	22	22
77	23, nylon	19	21
48	52, nylon	13	15
32	68, nylon	9	19

TABLE II. TOP SHRINKAGE OF BLENDED SLIVERS

Fiber composition		Top shrinkage (1-liter test)	
Wool (%)	Other (%)	10 min. (%)	20 min. (%)
100	0	42	54
89	11, viscose	47	54
78	22, viscose	46	54
50	50, viscose	47	54
26	74, viscose	47	55
0	100, viscose	2	3
91	9, Vicara	42	50
73	27, Vicara	38	48
52	48, Vicara	29	38
22	78, Vicara	9	13
0	100, Vicara	3	3
88	12, nylon	45	55
77	23, nylon	38	46
48	52, nylon	28	35
32	68, nylon	12	14
0	100, nylon	2	3

Laundering of Blended Tubing

The results of laundering tests are given in Table I. Since the tubing was only about 3 in. wide, the lengthwise shrinkage is considered to be more reliable than the widthwise shrinkage.

The data reveal the marked differences in the feltability of the blend, depending upon the nature and amount of the non-wool fiber present. The shrinkage is seen to increase as the viscose content increases, an effect which is consistent with the observations of Greenwood [5], Hall [6], and Whewell [14]. With increasing nylon content, on the other hand, the felting of the knit tubing decreases progressively, the nylon acting as a true diluent to the wool, which is in agreement with the data of Bennett [2]. The fabrics made from the Vicara blends felt much like the all-wool tubing until the wool content is decreased to less than 50%, at which point a decrease in laundering shrinkage occurs. It is probable that for other constructions the fiber compositions at which the decrease in felting appears may differ somewhat from those given here. However, the present results are believed to represent the general trends of the effect of blending on the laundering behavior.

Applicability of Top Shrinkage Test

This test consists of subjecting a sliver sewed into a cheesecloth sock to wet mechanical action in a tumble jar, and measuring the length change with time. For this purpose, 1 liter of water was used as the felting liquor, and measurements were made at 10 and at 20 min. of tumbling. The top shrinkage data are given in Table II. The over-all agreement between the top shrinkage results and those for the laundering of knit fabrics is seen to be close. The viscose blends are at least as feltable as the all-wool top up to 75% viscose content, and nylon decreases the felting of wool in proportion to the nylon content. However, in the top test, Vicara is seen to resemble nylon in depressing the feltability of the wool, a result which is not quite consistent with the felting results on the tubing.

Mechanism of the Felting of Blends

A possible mechanism for the effect of fiber type on the felting of blends can be given in terms of the mechanical and "frictional" properties of the fibers. It is now generally agreed that the felting of wool is a consequence of the scaly surface of the fiber, the imbricated surfaces providing bearing areas for fiber migration. When a wool fiber is in contact with a smooth, nonscaly fiber, the type of bearing surface depends upon the ease with which the fiber surface is deformed by the scale edge. A soft, swollen fiber might be expected to provide better "traction" for the motion of the wool; Speakman [11] noted the enhanced feltability of wool blends containing synthetic protein fiber (presumably of an easily swellable type) in which the wool fiber can migrate easily in the plastic matrix. Conversely, a fiber with a

smooth, hard surface hinders the wool movement by statistically diminishing the number of wool-to-wool contacts.

Although direct measures of deformability in this sense are not at hand, it may be assumed that the loads required to extend the wet fiber 2% are a measure of this fiber property. The values for wool, viscose, Vicara, and nylon are: 0.14, 0.05, 0.20, and 0.4 g./den., respectively. The data for transverse swelling in water place these fibers in the same ranking. Using this criterion, the wet viscose fiber can be seen to be more easily deformed than the wool and, hence, presumably deformed by it under the felting stresses. Vicara and wool are similar with regard to ease of deformation, whereas the nylon fiber is considerably stiffer in the wet state. The fact that some of the viscose blends felt to a greater extent than wool alone suggests that the wool-rayon fiber contact may be even better than that between wool fibers due to the surface plasticity of the rayon.

This view is consistent also with the fiber friction measurements reported by Olofsson and Gralén [9], who determined the apparent kinetic friction of wool, rayon, and nylon fibers against a wool fiber. Their data show that the directional frictional effect for the rayon-wool pair is equal to that for a wool-wool pair, whereas that for the nylon-wool combination is appreciably less, so that the latter blend might be expected to be less feltable.

The case of "blends" of wool and shrink-resistant wool is of interest in this connection. It has been shown [8] that the addition of even a small percentage of untreated wool to heavily chlorinated shrink-resistant stock results in a substantial increase in the feltability of the blend. It is believed that the mechanism is analogous to the case of viscose-wool. The overtreated wool has an easily swellable surface which is readily deformed when wet. The untreated wool can thus migrate more effectively in this type of soft, plastic matrix than it can when surrounded by more rigid nondeformable fibers such as nylon.

In the preceding discussion it was assumed that it is the deformability of the surface of the blending fiber which determines whether a feltable or nonfeltable blend will be produced. It is clear that a fiber of low modulus will respond more easily to the bending and twisting forces encountered in laundering, and this could also facilitate fiber entanglement. It is not possible to separate the mechanisms on the basis of the present data, and, in fact, tensile stiffness is assumed to be a measure of the over-all deformability of all kinds.

It was considered of interest to examine the felting behavior of some blends in which the ease of deformation of one of the components was altered. In the case of a nylon-wool mixture, a dilute cresol solution would be expected to swell and soften the nylon to a greater extent than the wool, and the resulting felting should be increased. In contrast, formaldehyde treatment is known to increase the modulus and decrease the swellability of viscose, and, hence, such a treatment should decrease the feltability of a viscose-wool blend.

The results of such a series of experiments are shown in Table III. In the first series, an all-wool top and a nylon-wool blend were subjected to the top shrinkage test using water and 2% *m*-cresol as the felting mediums. In the second series, a viscose-wool blend was subjected to a formaldehyde treatment for 30 min. at 80°C using 5% formalin at pH 7. The samples were then subjected to the top shrinkage test using water as the felting medium.

The use of *m*-cresol solution, instead of water, as the felting liquor is seen to increase the feltability of both the all-wool and the nylon blended top as a result of the increased swelling in this medium [4]. The increase of feltability is more marked in the blend, however, presumably due to the greater effect

TABLE III. THE FELTING OF BLENDED TOPS IN WHICH THE DEFORMABILITY OF THE SYNTHETIC COMPONENT WAS MODIFIED

Sample	Felting medium	Top shrinkage (1 liter, 10 min.) (%)	Change in top shrinkage due to modification (%)
100% wool	water	42	—
100% wool	2% *m*-cresol	46	+10
77% wool + 23% nylon	water	38	—
77% wool + 23% nylon	2% *m*-cresol	48	+26
78% wool + 22% viscose	water	44	—
78% wool + 22% viscose, HCHO-treated	water	32	−27

sult of the increased swelling in the medium [4]. noted that plasticizing agents may be used with acetate-wool blends to enhance milling. King [7] observed that swelling of the reference rubbing surface increases the friction and the friction difference with unswollen wool fibers. Formaldehyde treatment of the viscose-wool blend is shown to effect an appreciable decrease in the top shrinkage, presumably as a consequence of the decreased swellability of the viscose due to this cross-linking treatment.

The Role of Staple Length

In the course of this work, slivers were obtained which contained varying proportions of cotton and wool, corresponding to compositions of approximately 25%, 50%, and 75% cotton. It is important to note that the wool had to be cut to about 1¼ in. in order to prepare these blends in sliver form. When these were subjected to the usual top shrinkage test, it was found that the specimen did not shrink in the length dimension in the normal manner, although the slivers were obviously in a felted condition—that is, the usual length shrinkage did not occur, yet the fibers were interlaced and matted and could not be readily separated from one another without rupture. Estimates of the degree of felting of the blends were made by determining the increase in the tensile strength of the felted sliver after tumbling in the top shrinkage test; by this means the slivers containing 25% and 50% cotton were estimated to be roughly equal in feltability and that containing 75% cotton was found to be about half as feltable.

The results were reminiscent of the effect of staple length in wools of differing geographical origin [10], in which short staple was associated with lower feltability. Another example of this same type of effect was observed in these laboratories in comparing the felting in the top shrinkage test of "preparer" sliver with that of the top from which it was made; in the former stage, just prior to the combing operation, the sliver contains all the short-fibered noils and shrinks as much as 50% less in length than the fully combed top.

This interesting phenomenon prompted some additional work along these lines. A commercial wool top (60's grade, mean staple length approximately 2¾ in.) was obtained, and a new sliver was prepared from a portion in which the staple was cut at about 1½ in. Top shrinkage tests (Table IV) indicated that, although considerable felting had taken place in the short-staple top, the shrinkage in length as usually measured was much lower than that found in the uncut top.

Yarns were spun from each of these tops as nearly identical as possible, and specimens of flat knit tubing were prepared from them as before. The shrinkage in laundering after relaxation is shown in Table IV. The data indicate the profound effect of the staple length on the laundering shrinkage, which was decreased substantially in the short-staple sample.

The results presented here are consistent with those of Speakman, Stott, and Chang [12], in which fulling of a cloth made from a long filtered Wensleydale wool was greater than that of fabric made from the same wool cut to a shorter length. Some doubt was raised as to the general applicability of these conclusions by the work of Speakman and Sun [13], which indicated that short-staple Merino wool milled more rapidly than did a wool of about twice the mean staple length. It is to be noted, however, that the differences in feltability were not very great in the latter case, and that the wool of average short-staple length did contain an appreciable number of long fibers. It should be emphasized that the short-staple fabric does become stiffer and somewhat boardy, which is characteristic of a felted structure, but with much smaller change in linear dimensions.

The practical implications of this effect are not completely clear from the present data. Other characteristics of a cloth are obviously also influenced by staple length—*e.g.*, strength, abrasion-resistance, and handle. In order to evaluate this phenomenon more clearly, more quantitative studies of the role of staple length on felting are now in progress.

TABLE IV. SHRINKAGE OF WOOL AS A FUNCTION OF STAPLE LENGTH

	Top shrinkage (1 liter, water)		
Sample	4 min. (%)	10 min. (%)	20 min (%)
Long-staple top	24	43	52
Short-staple top	10	15	19

	Laundering shrinkage of tubing		
	Length (%)	Width (%)	Area (%)
Long staple	21	20	37
Short staple	3	11	14

Summary

1. The shrinkage in laundering of knitted samples containing wool blended with varying amounts of nylon, Vicara, and viscose was studied. The nylon acts as a true diluent, the felting decreasing as the proportion of nylon in the blend increases. The addition of viscose tends to increase the feltability in the construction studied, even when half the fiber is viscose. The Vicara blends are intermediate in behavior.

2. The diverse behavior of the various fibers when blended with wool may be explained by the plastic nature of their surfaces, and by the relative ease with which the fibers are bent and twisted in laundering. Those fibers which are easily deformed by the stresses encountered in the felting process (*e.g.*, viscose) do not inhibit shrinkage in blends, and may enhance it by providing a soft bearing surface for neighboring wool fibers. The felting of such blends may be decreased by decreasing the swellability of the non-wool component by means of a cross-linking treatment. Blends with nylon, which are low in feltability due to the relative difficulty with which this fiber is deformed, may be made to felt more easily by the use of swelling agents such as cresol.

3. Staple length is shown to affect the feltability of wool considerably. A fabric made from short-staple wool became thick and boardy in laundering, although this was not accompanied by the usual large changes in linear dimensions.

Acknowledgment

Grateful acknowledgment is made to Mrs. Virginia A. Moran and to Allen H. Adkins for assistance in making most of the measurements reported.

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Letters to the Editor

Short communications in the form of Letters to the Editor are intended to provide prompt publication of significant new research results and to permit an exchange of views on papers previously published in the JOURNAL. These communications are not submitted to formal review as are research papers, and the editors do not assume any share of the author's responsibility for the information given or the opinions expressed. When work previously published in the JOURNAL is the subject of critical comment, the authors of the original paper are given an opportunity to submit a reply, which will be published concurrently when possible.

Freezing Point Lowering and Solubility Curves of Cellulose Fibers

UNIVERSITY OF MANCHESTER
College of Technology
Manchester, England
December 1, 1952

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

According to a current hypothesis, part of the water imbibed by fibers is considered to be present in a solution of the macromolecules [2, 8] of the noncrystalline regions. If this hypothesis is accepted, a number of verifiable deductions can be made. Thus, fibers should show properties characteristic of solutions. One such property is the lowering of the freezing point of the solvent—in this case, water. Another property is the temperature dependence of the concentrations of saturated solutions. If these properties are shown by the water present in the noncrystalline parts of moist fibers, then the temperature-concentration relationships should be those shown in a binary phase diagram. No attempt appears to have been made to examine whether a system of fibers and water leads to such a phase diagram. Investigations of the freezing of moist cellulose fibers have been made by Magne *et al.* [4, 5] with a different objective to that of the present communication. Their results are not directly comparable with the ones given here, since in order to make a comparison a number of doubtful assumptions would have to be made.

Heat is evolved when a binary system in the liquid region is cooled to the temperature at which solid begins to separate. The usual method of measuring the temperature at which the solid appears—that is, the freezing point—is by determination of the inflection on the cooling curve [1]. Both the low temperature branch—that is, the lowering of freezing point curve—and the high temperature branch—that is, the solubility curve—can be investigated. The latter can be examined conveniently by using a rising temperature instead of a falling one, but with otherwise similar techniques.

Fibers with a known moisture content were placed in a stoppered and insulated container, and this in turn was immersed in a mixture of acetone and solid carbon dioxide for cooling curves and in a boiling water bath for heating curves.

The temperature of the fibers was measured by a calibrated Thermistor giving an accuracy of reading of 0.1°C. The fibers investigated were viscose and cotton. Typical cooling curves for the viscose fibers obtained in this way are shown in Figure 1. The breaks in the curves corresponding to the separation of ice can be seen clearly. The curve for 50%

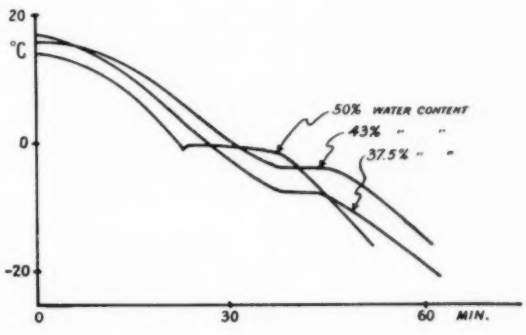

FIG. 1

water content also shows evidence of supercooling. It was observed that there was a tendency for the approximately horizontal parts of the curve to become shorter the lower the moisture content. It will be seen that the breaks of the cooling curves fall with progressively lower moisture content. Both the shortening of the approximately constant temperature portions of the curves and the lowering of the temperature at which this occurs with decreasing moisture content agree with the solution hypothesis. When the levels of the breaks in the cooling curves are plotted against the concentrations of water, a curve is obtained which is similar to the lowering of freezing point curve of a binary system. The lowering of freezing point curves for viscose and cotton fibers obtained in this way are shown by *AB* and *DE*, respectively, in Figure 2. The corresponding curve for sucrose and water, *FG*, from the published data [3] is plotted for comparison. It will be seen that all the three lowering of freezing point curves are similar except that the curves pertaining to the fibers do not start from the 100% water origin as does the curve for sucrose. This is because there is an upper limit to the water imbibed by fibers, which is usually expressed as saturation regain. Any water in excess of this is in the capillary spaces amongst fibers and not imbibed by the fibers themselves [6]. In the present investigations the assemblies of fibers used contained no significant amount of capillary water.

The high temperature branch of the phase diagram for viscose fibers is shown by *BC* in Figure 2. This is closely similar to the corresponding curve for sucrose plotted from the published data [3] and shown by *GH* in Figure 2. This is the solubility curve of sucrose, and it is seen that the curves for viscose fibers and sucrose are similar.

It is interesting in Figure 2 to compare the water contents required to produce the same lowering of freezing point in each of the three systems. These are, in order of increasing water content: cotton, viscose, and sucrose. Furthermore, it will be observed that the content of water in viscose is approximately twice as high as that in cotton for the same lowering of freezing point. According to the solution hypothesis, this can be explained readily as being caused by complete solution in the case of sucrose and by there being approximately twice as much noncrystalline material in viscose as in cotton, so that it requires twice as much water to produce the same concentration of solution in viscose as in cotton. This ratio

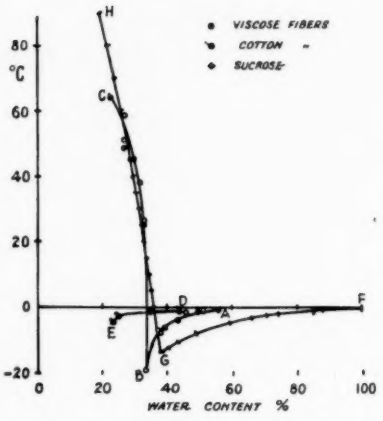

FIG. 2

of the noncrystalline matter in the two kinds of fibers agrees with the literature values.

The high temperature branch of the viscose-water system is very steep and lies in a small concentration range between about 20% and 30% moisture. According to the solution hypothesis, a moisture content in this range would be the one required to dissolve and liberate the noncrystalline molecules. The presence of a water concentration just sufficient to dissolve the noncrystalline cellulose would favor internal rearrangements of fiber structure without excessive separation of structural elements. It is interesting to find this deduction confirmed, since a moisture content of about 25% was found to permit the maximum consolidation of fiber structure on heating viscose fibers [7].

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J. M. PRESTON
M. V. NIMKAR

Raw Cotton: Variation within Bales and within Shipments

FIBER RESEARCH INSTITUTE T.N.O. OF THE
NATIONAL COUNCIL FOR INDUSTRIAL RESEARCH
Enschede, Netherlands
December 3, 1952

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

In cooperation with a spinning mill, this Institute is engaged in observing the relationships between cotton fiber properties and yarn properties in actual mill practice. In connection with this work, we have accumulated a considerable amount of data on the variation *within shipments* between high-density bales of raw cotton.

Bales were sampled by taking four subsamples of about 50 g. each from the bale as it lay ready for use in the opening room. Two subsamples were taken from the upper half of the bale, and two from the lower portion; none of these were from the sides of the bale. The four subsamples together, after randomizing, served as one bulk laboratory sample.

Variation within Bales

Since the variation within bales, from bale to bale, fluctuates between rather wide ranges, the above sampling procedure was chosen arbitrarily. In preliminary studies on sampling of bales, in which 57 bales of 24 shipments were used, 10 samples of 20 g. each were tested per bale. The results given in Table I were obtained. No data have been published, as far as we know, on the influence of the size of the sample on the variation within bales, but after the results given in Table I, our data on bales were considered to be sufficiently accurate for our purpose.

Variation *within Shipments* between Bales

The shipments consisted of cotton ordered on description or on sample; the quality of the cotton consequently had not been specified in terms of fiber properties. The shipments came from various ship-

TABLE I. CUMULATIVE FREQUENCY (%) OF THE COEFFICIENT OF VARIATION WITHIN BALES

Coeff. of variation (%) up to:	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	21.0
Micronaire	9	40	65	75	83	86	89	91	93	98	100
Fibrograph (u.h.m.)	2	57	93	100							

TABLE II. VARIATION *WITHIN SHIPMENTS* BETWEEN BALES

No.	No. of bales tested	Grade	Staple length, nominal (in.)	Origin	Coeff. of variation (%) Fibrograph (u.h.m.)	Micronaire	Pressley index
1	14	SM	1	?	4.9	9.1	3.8
2	17	SM	1	U.S.A.	2.3	7.5	5.4
3	6	SM	1	?	8.6	9.0	3.7
4	64	?	$\frac{31}{32}$	Togo	2.5	3.8	4.5
5	42	?	?	Brazil	2.0	4.2	4.1
6	26	SM	1	U.S.A.	6.3	10.1	6.9
7	14	SM	1	U.S.A.	3.1	5.4	6.0
8	8	SM	1	U.S.A.	2.6	9.3	6.5
9	34	SM	1	U.S.A.	4.6	10.0	7.8
10	11	?	$\frac{31}{32}$	Togo	2.1	16.2	5.9
11	26	SM	1	U.S.A.	3.7	10.4	6.2
12	24	?	$1\frac{1}{32}$	U.S.A.	3.6	10.7	4.7
13	30	GM	$1\frac{1}{32}$	U.S.A.	3.7	11.7	3.6
14	16	SM	1	?	3.4	7.3	3.3
15	6	?	?	?	1.8	3.8	2.7
16	12	GM	$1\frac{1}{32}$	U.S.A.	3.5	5.8	5.8
17	6	GM	1	U.S.A.	2.9	5.4	6.4
18	26	GM	$1\frac{1}{32}$	U.S.A.	3.9	10.3	7.0
19	48	SM	$1\frac{1}{32}$	Mexico	3.3	8.3	6.9
20	47	SM	1	U.S.A.	5.0	15.2	6.1
21	23	GM	1	U.S.A.	4.8	13.8	8.8
22	74	SM	$1\frac{1}{32}$	U.S.A.	4.8	12.2	7.6
23	51	?	1	Brazil	2.8	21.2	5.4
24	26	?	1	Brazil	1.9	2.6	6.2
25	5	GM	$1\frac{1}{32}$	U.S.A.	7.3	18.7	7.1
26	16	GM	1	U.S.A.	4.1	12.3	6.5
27	25	GM	1	U.S.A.	4.6	10.1	6.0
28	27	?	1	Brazil	1.9	3.9	3.6
29	18	Brt.M	$1\frac{1}{32}$	U.S.A.	4.1	8.8	2.7
30	18	Brt.M	$1\frac{1}{32}$	U.S.A.	3.2	12.8	5.2
31	6	SM	1	Brazil	7.9	16.0	1.7
32	30	GM	1	Irak	1.6	15.2	5.7
33	33	GM	$1\frac{1}{32}$	U.S.A.	3.2	12.8	5.4
34	37	?	$1\frac{1}{16}$	U.S.A.	3.9	11.8	5.7
35	21	SM	$1\frac{1}{16}$	U.S.A.	3.3	8.4	3.8
36	21	GM	$1\frac{1}{16}$	U.S.A.	3.5	8.8	4.7
37	20	SM	$1\frac{1}{16}$	U.S.A.	2.4	7.7	4.0
38	8	MG	$1\frac{1}{16}$	U.S.A.	1.5	10.0	5.3
39	53	MG	$1\frac{1}{16}$	U.S.A.	3.5	13.9	5.3
40	14	SM	$1\frac{1}{16}$	U.S.A.	3.4	7.6	8.4
41	63	SM	$1\frac{1}{16}$	U.S.A.	2.8	14.9	8.5
42	14	GM	1	Irak	1.8	17.2	3.0
43	46	GM	$1\frac{1}{32}$	U.S.A.	3.3	10.1	8.7
44	44	SM	$1\frac{1}{16}$	U.S.A.	3.9	12.1	8.7
45	50	GM	?	U.S.A.	2.8	7.4	9.4
46	43	MG	$1\frac{1}{16}$	U.S.A.	4.4	10.9	4.9
47	15	SGM	$1\frac{1}{8}$	U.S.A.	2.6	11.2	4.7
48	15	SGM	$1\frac{1}{8}$	U.S.A.	3.5	13.8	2.9
49	15	SGM	?	U.S.A.	3.2	13.0	4.5
50	15	?	$1\frac{1}{16}$	U.S.A.	3.2	7.9	4.8
51	21	?	$1\frac{1}{16}$	U.S.A.	3.3	13.8	3.2
				Mean	3.6	10.5	5.5

pers, and originated from widely diverging locations; the period of harvesting could not be traced in most instances. From each shipment a sufficient number of bales were tested in order to obtain a fair estimate of the coefficient of variation between bales in the shipment; no shipment was larger than 200 bales.

In this country there is considerable interest for working with even running cotton, and, consequently, one wonders how far the shippers are able to narrow down the variation within shipments without having to resort to instrument testing of individual bales.

Several shipments on which the variation is given in Table II in our opinion are not much more than an agglomeration of bales taken at random. In connection with the tendency to use even running cotton, it would be of considerable value to obtain more data on variation in lots, between bales, in order to come to a general accepted opinion on which variation may be called large, normal, or small for shipments made up on the judgment of the ordinary cotton classer.

The Fiber Research Institute T.N.O. would highly appreciate an exchange of data and opinions on this subject, and hopes this letter will stimulate publications.

Acknowledgment

We are writing this letter by mutual arrangement with the sponsor of this research project, the Netherlands Association of Cotton Spinners "Garencentrale."

We wish to thank the Director of the Fiber Research Institute T.N.O., Mr. J. R. H. van Nouhuys, for his encouragement and suggestions during the course of this work.

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J. ALBERTS

INDUSTRIAL SECTION

Characterization of Warp Streaks in Woven Fabrics—Development and Use of the Streakmeter

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Introduction

Warp streaks constitute one of the major defects in woven fabrics made from continuous-filament yarns. It is generally accepted that these streaks arise from a number of specific causes, which can be divided into two main classifications—yarn variations and fabric variations. For example, pronounced variations in denier, luster, or dye receptivity among the yarn ends of a warp will produce streaks. On the other hand, nonuniform tensions and the use of poor reeds or other improper procedures and equipment in the preparation of fabrics will also produce streaks, even though the physical characteristics of the yarns are initially uniform. Warp streakiness resulting from the use of faulty reeds was well illustrated in a recent article by S. W. Brainard.*

When most woven fabrics are inspected visually, it is practically impossible to decide which of the streaks are due to yarn variations and which are due to fabric manufacturing variations. Furthermore, the exact location of individual streaks cannot be determined by ordinary visual inspection; it is practically impossible to decide whether individual streaks arise from the yarn ends or from nonuniform spacings between the yarn ends. In order to permit precise characterization of individual streaks as to location, type, and intensity, an instrument called the "Streakmeter" has been developed. The present communication presents information on the development, construction, and some of the possible uses of the Streakmeter for characterizing warp streaks in woven fabrics. Fabric producers can assemble a similar instrument as an aid in diagnosing the types and possible causes of streaks in fabrics.

* *Rayon and Synthetic Textiles* **32**, No. 7, 31, 34 (July 1951).

Types of Streaks

In the past, a fabric was said to be streaky when a warp yarn or group of warp yarns appeared different in color than the surrounding regions of the fabric. It is now known that, in addition to yarn color, there are at least two other types of warp streaks. A streak can result from a yarn or yarns which form a configuration different than surrounding yarns, as in the case of a "tight" warp yarn. Another type of streakiness, sometimes called "reediness," arises from variable spacings between the warp yarns.

Experimental Instrument Development

In the first attempt to rate and identify streaks instrumentally, taffeta fabrics were mounted on stripped spectrographic plates and a trace was taken across the warp yarns or ends with a recording microdensitometer (slit dimension = $20\,\mu \times \frac{1}{16}$ in.). This initial work confirmed the postulate that nonuniform spacings between yarn ends in the fabric were extremely important in breaking up the homogeneity and evenness of the fabric appearance. Each dent was detected accurately. However, visual differences of yarn color were not detected as variations in optical density, probably because transmittance of light through the yarn ends was very low.

Since fabrics are customarily viewed with reflected light and because of the deficiency mentioned above, it was obvious that measurements of reflected light from each warp yarn and space between them were needed. To test such a case, reflectance photographs were taken of streaky fabrics with incident light at 45° and the camera normal to the fabric. Microdensitometer traces of these photograph negatives showed the exact location and the relative intensities of individual streaks. The variations in the microdensitometer trace from different sections of the fabric correlated well with the visual rating of streakiness.

This work brought out the postulate that even if all warp ends were dyed to the same color, the fabric could be streaky because of (*a*) fabric configurational variations, (*b*) nonuniform spacings between the yarn ends, or (*c*) a combination of both (*a*) and (*b*). In addition to inadequate control of lighting conditions, this method involved examinations of only exceedingly short (0.03 in.) lengths of yarn. It therefore appeared that a Streakmeter should be based on direct reflectance measurements of longer sections (0.1–0.2 in.) of warp yarns, with the slit narrow enough to scan only part of a yarn end at one time.

From the foregoing discussion, it was apparent that some rapid, reproducible method of scanning a fabric in reflected light was needed. Of all the methods considered, the most advantageous was a reflectance photoelectric system. However, the problem of distinguishing the individual yarn ends and spaces between the yarn ends and still securing enough illumination to actuate a photoelectric circuit remained to be solved. One solution to the problem would be the detailed scanning of an enlarged nonaberrated image of the brightly illuminated fabric. The Readex Microfilm Reader,* which brightly illuminated the sample and projected an enlarged, reflected, and detailed image of the fabric section under study on a ground-glass viewing port, appeared to answer these preliminary specifications. A simplified version of the optical system of the Readex Reader is shown in Figure 1. A constant-speed motor drive was attached to the horizontal drive control to provide a carriage travel of 1 in./hr. The basic features of the Streakmeter, therefore, consisted of a motorized Readex Microfilm Reader which gave an enlarged (12.5–18 ×) and projected image of the fabric,

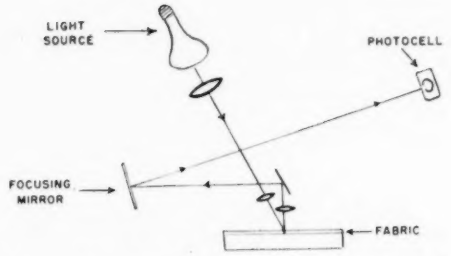

FIG. 1. *Optical system of the Readex Microfilm Reader.*

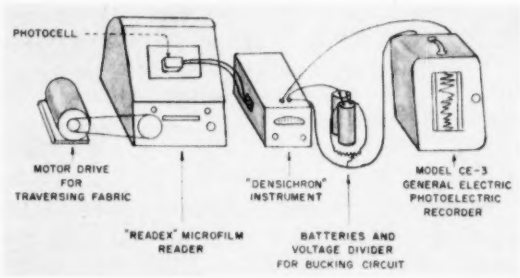
PHOTOCELL
MOTOR DRIVE FOR TRAVERSING FABRIC
"READEX" MICROFILM READER
"DENSICHRON" INSTRUMENT
BATTERIES AND VOLTAGE DIVIDER FOR BUCKING CIRCUIT
MODEL CE-3 GENERAL ELECTRIC PHOTOELECTRIC RECORDER

FIG. 2. *Schematic diagram of the Streakmeter.*

a photoelectric pickup, and a high-speed recorder. In the instrument described here, the image was scanned with the photocell probe of a Densichron * photoelectric receiver, which was mounted permanently at the focal plane of the optical system. Since the Readex Reader was equipped to traverse the fabric, the fabric was moved instead of the photocell. The photocell was modified by replacing the normal face cover with a cover in which a narrow (0.008 in. wide × 1 in. long) slit had been cut. This permitted the photocell to "see" less than one-fourth of the width of a warp yarn (70–34–7Z) while covering eight to ten filling ends, thus randomizing the effect of filling yarn variation. The photoelectric impulse developed in the Densichron was sent to a G.E. (Model CE-3) milliampere photoelectric recorder having a response time of less than 1 sec. for full-scale reflection and a chart speed of 6 in./min. The signal from the Densichron, when set at maximum sensitivity, was too strong for the recorder. However, the variations of the signal were approximately of the order of magnitude which would correspond to the full-scale deflection of the recorder. Therefore, by suppressing the base current from the Densichron without reducing the current variations, the recorder could be used and

* This microfilm projector is not produced commercially at the present time. An instrument with a similar optical system (Figure 1) should perform satisfactorily.

* Distributed by W. M. Welch Scientific Company.

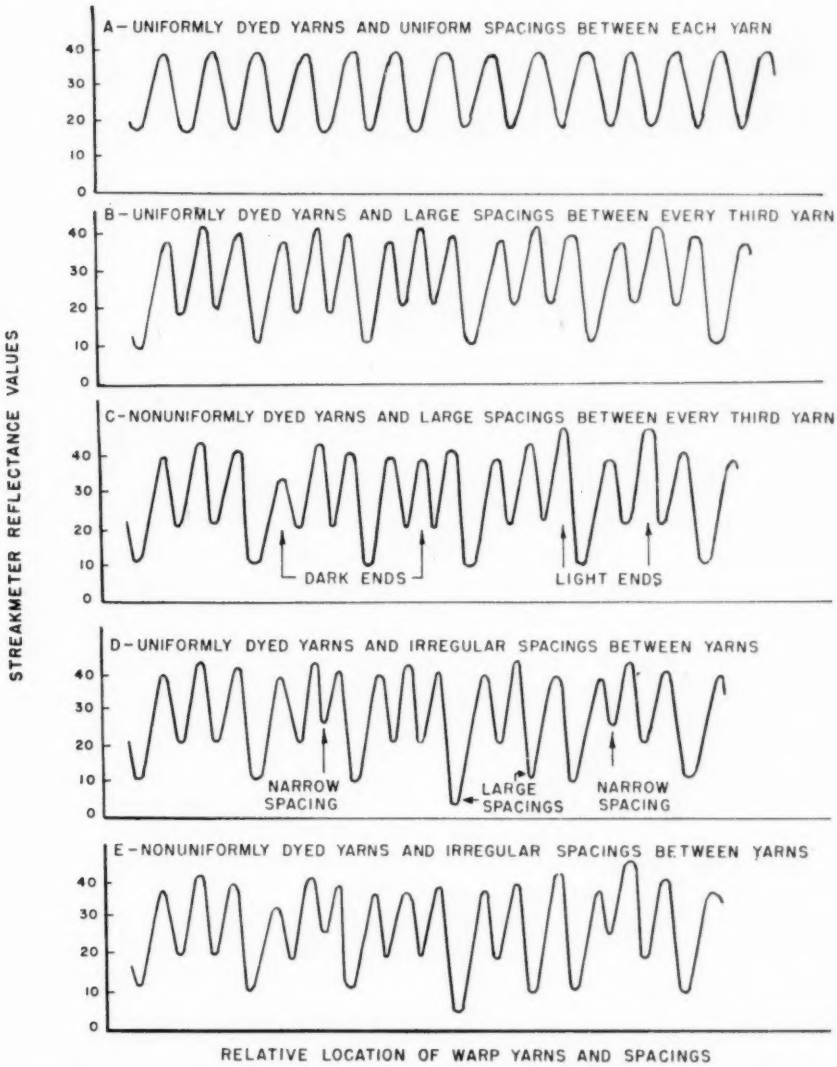
A – UNIFORMLY DYED YARNS AND UNIFORM SPACINGS BETWEEN EACH YARN
B – UNIFORMLY DYED YARNS AND LARGE SPACINGS BETWEEN EVERY THIRD YARN
C – NONUNIFORMLY DYED YARNS AND LARGE SPACINGS BETWEEN EVERY THIRD YARN
DARK ENDS
LIGHT ENDS
D – UNIFORMLY DYED YARNS AND IRREGULAR SPACINGS BETWEEN YARNS
NARROW SPACING
LARGE SPACINGS
NARROW SPACING
E – NONUNIFORMLY DYED YARNS AND IRREGULAR SPACINGS BETWEEN YARNS
0
10
20
30
40
STREAKMETER REFLECTANCE VALUES
RELATIVE LOCATION OF WARP YARNS AND SPACINGS

FIG. 3. *Hypothetical Streakmeter records, illustrating effects of variable-appearing yarns and spacings between warp yarns.*

would record only the impulse variations. This was accomplished by using a bucking circuit consisting of two 1.5-volt dry cells and a voltage divider.

A schematic diagram of the Streakmeter is shown in Figure 2.

Operation of the Streakmeter

A sample 4 in. × 5 in. in area was cut from a representative section of the fabric to be examined. Loose warp yarns were then removed from one edge until one yarn extended across the full width of the sample. This point in the sample served as a reference for later identification of yarns in the Streakmeter record. The fabric sample was then placed under the glass positioning plate of the Readex film carriage. A nonlustrous black surface was found to be the best background underneath the fabric. Care was required in aligning the fabric sample so that the

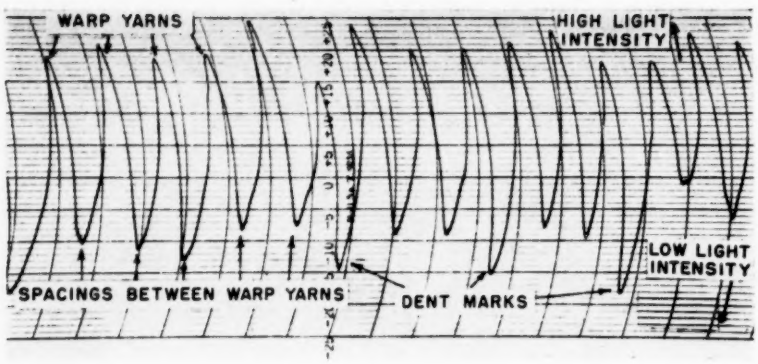

FIG. 4. *Streakmeter record of a streaky fabric made from nylon yarns.*

images of the warp yarns were parallel with the slit in front of the photocell. After the lighting, photoelectric, and recording circuits had been energized sufficiently long to be stable, the drive for moving the fabric sample was started. When fabric samples of different colors were studied, readjustment of the Densichron sensitivity and bucking circuits were required to obtain the desired amplitude and location of the recorded trace.

Interpretation and Use of Streakmeter Records

In this study, a streak was considered to be formed by a yarn end or an open space which was visibly different in appearance from surrounding yarn ends or open spaces. The Streakmeter produced a record of light reflectance values from each individual yarn end and each space between yarn ends.

The traces which might be expected from the measurements of the light reflectances from single warp ends and from single spaces between warp ends of yarn, with typical variations, are shown schematically in Figure 3.

The reflectance trace for a theoretically perfect fabric without streaks would be an undulating curve of uniform amplitude and periodicity (Figure 3(A)). The maxima, representing high intensities of reflected light, would originate from the yarn ends; the minima, representing low intensities of reflected light, would originate from the spaces between yarn ends. A typical commercial fabric construction (involving reeding of three ends per dent) is illustrated in Figure 3(B), wherein large spacings exist between every third yarn end, giving pronounced minima at these points. Even if the yarns were inherently uniform in dyeing rate, commercial dyeing practices would result in the first and third yarns in each group of three yarn ends being slightly darker than the middle yarn; this would produce slightly higher maxima for the middle yarns. It should be emphasized that this fabric would not appear streaky to the eye because the nonuniformities of yarns and spacings are uniformly repetitive and sufficiently close together to be undetectable visually.

Figure 3(C) represents a fabric wherein light and dark dyed warp yarns are randomly located in the fabric, resulting in visible streakiness. Visible streakiness can also be obtained from irregular spacings between warp yarns (Figure 3(D)) even though the yarns are essentially uniformly dyed. Most commercial fabrics exhibit both types of streakiness—nonuniformly dyed yarns and irregular spacings—as illustrated in Figure 3(E).

The Streakmeter record of a streaky taffeta fabric in which the warp consisted of 70–34 Type 200 nylon yarns having 7 t.p.i. twist is shown in Figure 4. The nonuniform maxima and minima show that, in this case, streaks originated from both nonuniformly dyed yarns and from irregular spacings. A sample of the Streakmeter record of a streaky taffeta fabric made from Dacron * polyester fiber yarn is shown in Figure 5, again illustrating streaks of both types. The circles and triangles of this chart represent readings of repetitive Streakmeter records made from the same warp yarns at different locations in the warpwise direction. The similarity of relative values for each yarn and spacing in the three records proved the reproducibility of the Streakmeter records. Examination of Streakmeter records, such as those shown in Figures 4 and 5, showed that it could be decided whether a selected visible streak in the fabrics originated from a yarn end or an open space (or

* DuPont trademark.

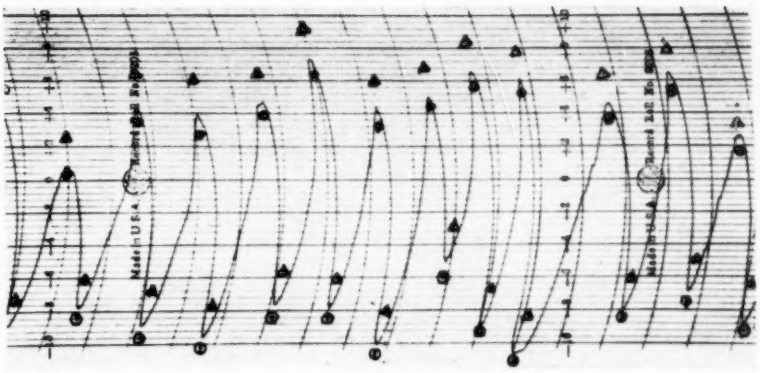

FIG. 5. *Streakmeter record of a streaky fabric made from Dacron polyester fiber.*

both). If an abnormally high maximum was shown by the Streakmeter record at the fabric location where a light streak was visible, there was no doubt that the streak originated from a light-appearing yarn (low dye content or high luster). As an additional example, a visible dark streak could originate from a wide open space which gave an abnormally low light reflectance value at a minimum on the Streakmeter record. By counting the number of warp ends or open spaces from the streaks to the reference points in the fabrics and on the record, the exact location of individual streaks was obtainable. This ability to determine the exact origin and location of individual streaks is extremely important when a characterization of yarns forming streaks is undertaken. This exact information is not obtainable by ordinary visual inspection, and therefore represents unique attributes of the Streakmeter.

Since the Streakmeter records presented relative values of light reflectances from each yarn end and open space, a numerical value could be assigned to each streak from a yarn end by measuring the numerical difference in light reflectances between the streak yarn (or open space) and its surrounding yarn ends (or open spaces). To convert these numercial color differences into standardized units, the Streakmeter values could be calibrated and converted into N.B.S. units * for the color of the fabric under study. In summary of the above, the Streakmeter records can be used to obtain the following information concerning individual streaks: (*a*) exact location; (*b*) origin, whether from yarn ends or from open spaces; and (*c*) numerical rating of the intensity or prominence.

* National Bureau of Standards unit of color difference.

Two additional types of important information were obtainable from the Streakmeter records. They were (*a*) a numerical rating of the over-all streakiness of a fabric, and (*b*) assignment of the fractions or percentages of streakiness originating from yarn ends and from open spaces. Methods and assumptions for these calculations are discussed below.

Based upon the previous definition of individual streaks, the over-all streakiness of a fabric originated with and was proportional to the variations in appearance of consecutive yarn ends and open spaces. The variation of reflectances of consecutive yarn ends was calculated as a standard deviation value, σ_e. This σ_e value was calculated from the reflectance differences between consecutive maxima values of the Streakmeter record. The σ_e value therefore represented the over-all streakiness originating from the yarn ends. The streakiness originating from the open spaces, σ_{os}, was calculated from the differences between consecutive minima values of the Streakmeter record. At least 200 yarn end and open space values were required to obtain reliable σ_e and σ_{os} figures. As discussed earlier and illustrated in Figure 3, a periodic variation of appearance, such as a large open space between every third yarn end, would not contribute to streakiness discernible by the eye. In this case of a periodic variation, a correction was made to each of the periodically different minimum values. The over-all streakiness, or streak rating, of the fabric was calculated as a numerical value from the formula $\sqrt{\sigma_e^2 + \sigma_{os}^2}$. Since the over-all streakiness of a fabric could be expressed as the above function of σ_e^2 and σ_{os}^2, the fractions or percentages of streakiness originating from the yarn ends and from the open spaces could be calculated. The percentage of streakiness originating from the yarn ends was

TABLE I. PROPORTIONS OF STREAKINESS IN FABRICS OF NYLON AND DACRON YARNS

Yarn	Streakiness due to yarn variations (%)	Streakiness due to spacing variations (%)
Nylon	52	48
Nylon	50	50
Nylon	43	58
Nylon	47	53
Nylon	60	40
Dacron polyester fiber	53	47

calculated from the formula

$$\frac{\sigma_e^2 \times 100}{\sigma_e^2 + \sigma_{os}^2}.$$

The percentage of streakiness originating from open spaces was calculated with σ_{os}^2 in the numerator of the above formula. Samples of fabrics made from nylon and Dacron yarns which showed objectionable streakiness were analyzed by the above procedure. Percentage values for the two types or origins of streakiness varied in the range of 40% to 60%, as shown in Table I. These values show that variations in appearance of open spaces can be as contributory to streakiness as the yarn ends in these fabrics.

To demonstrate that the Streakmeter would give valid streakiness values, or streak ratings, with respect to visual appearance, six carefully selected samples of rayon fabrics were studied. These six fabrics represented various degrees of streakiness according to an arbitrary scale based upon judgment through visual inspection. Figure 6 shows the plot of the visual and instrumental values for the streak ratings of these six fabrics. The good agreement between visual and instrumental values indicates that the Streakmeter provides quite accurate measurement of the streakiness of the visually standardized fabrics. It was therefore concluded that the Streakmeter can

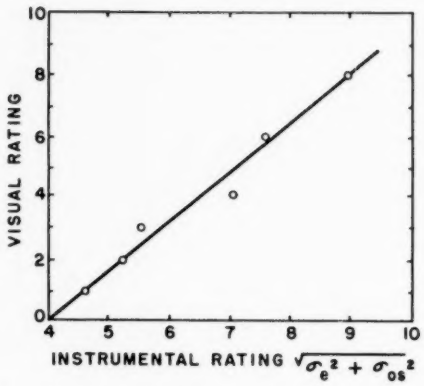

FIG. 6. *Visual vs. instrumental (Streakmeter) ratings of standardized rayon twill fabrics.*

be relied upon to measure streakiness and provide ratings similar to those judged by a trained observer.

Additional data derived from the Streakmeter records for these six rayon fabrics are presented in Table II. The second and third columns present σ_e and σ_{os} values for these fabrics. Neither of these sets of values correlate well with the visual streak rating values. The good correlation obtained with the sums of their squared values in the fourth column proves that both types or origins of streakiness must be considered when measuring over-all streakiness.

The fifth and sixth columns of Table II present percentage values of streakiness originating from the yarn ends and from the open spaces in these fabrics. The percentage values of streakiness originating from the open spaces are much lower for these fabrics than for those made from nylon or Dacron polyester yarns. This difference is believed to be due to the greater swelling values of rayon yarns, which enables irregularities in yarn spacings to be evened out during scouring and dyeing. Nylon and Dacron

TABLE II. DATA FROM STREAKMETER RECORDS OF RAYON FABRICS

Visual rating	σ_e	σ_{os}	$\sqrt{\sigma_e^2 + \sigma_{os}^2}$	Streakiness due to yarn variations (%)	Streakiness due to spacing variations (%)
1	4.15	2.07	4.64	80	20
2	4.95	1.73	5.24	89	11
3	5.06	2.27	5.54	83	17
4	6.40	2.94	7.04	82	18
6	5.90	4.72	7.56	61	39
8	7.44	3.92	8.92	78	22

yarn swell to a far lesser extent than rayon under ordinary scouring and dyeing procedures, and therefore spacing irregularities are not altered appreciably. This implies that extreme care must be taken in the manufacture of fabrics from nylon or Dacron yarns to insure that the irregularity of spacings is kept at a minimum in the gray fabric.

An interesting observation made from the Streakmeter records of typical fabrics of nylon and Dacron yarns was the large difference between reflectance values from yarn ends and from open spaces. This difference amounted to 15–20 N.B.S. units.* In other words, the detailed appearance of a fabric in the warp direction is an alternating series of very dark and very light lines, with the yarns forming the light lines and the spaces forming dark lines. At a normal viewing distance, the eye cannot discern the individual lines, but instead sees an average color blended from the two sets of lines.

Limitations and Potential Improvements

At the present stage of development, the Streakmeter has several limitations. The optical system gives images from only about $\frac{1}{10}$-in. lengths of the warp yarns on the photocell slit. A suggested improvement is the use of a cylindrical lens which would not give magnification in the warp yarn direction and would therefore permit a scanning length of about 1 in. of yarn.

Analyses of the Streakmeter records involve tedious reading of data from charts. Integrating equipment operated from the output of the photocell could be assembled to provide σ_e and σ_{os} values directly.

It is important to emphasize that the Streakmeter records have been used to detect and measure only two types of origins of streaks. The present records and interpretations do not permit assignment of specific causes to the streaks, such as nonuniform denier or nonuniform warping tensions. The σ_e values (variations in yarn and appearance) are not necessarily due to nonuniform denier or elongation values of the yarn as shipped from the yarn producer's plant. As an illustration, a light-appearing warp yarn need not be due to any property variation, but instead could be caused by nonuniform and excessive tension during the warping operation in the textile mill. On the other hand, variations of spaces, σ_{os}, between yarns could arise from nonuniform shrinkage or modulus of the yarns as well as from faulty textile mill equipment, such as uneven reeds. It is expected that additional fabric studies and improvements to the Streakmeter will permit assignment of some of the specific and detailed causes of individual streaks.

In spite of the above limitations, the Streakmeter gives yarn producers and textile mills an opportunity to classify and characterize streakiness in woven fabrics more thoroughly than was hitherto possible. Numerical ratings of over-all streakiness can be assigned to production fabrics in the textile mills. Individual streaks can be located precisely and identified as to type, which should permit eventual assignment of the cause. With well-known histories of fabrics and intelligent interpretation of the Streakmeter records, significant advances in the warp streak problem should be obtainable. It is expected that both yarn producers and textile mills can assemble equipment similar to that described herein, and that, with additional experimentation, improved techniques and more complete interpretations will be obtained.

Summary

An instrument called the "Streakmeter" has been developed to locate and characterize individual warp streaks in plain woven fabrics. The Streakmeter measures and records photoelectrically the relative intensities of light reflectances from each warp yarn and from each space between consecutive warp yarns. Visible streaks were shown to originate both from variable-appearing yarns and from variable-appearing spaces between yarns.

The Streakmeter records were used to calculate numerical ratings of the over-all streakiness of fabrics. These records were also used to calculate the proportions of streakiness originating from variable-appearing yarns and from variable-appearing spaces between yarns.

The ability to locate and characterize individual streaks and to determine the proportions of different types of over-all streakiness affords a more complete analysis of warp streaks than is possible with other known methods. The Streakmeter can be used by fabric producers to evaluate commercial fabrics and to aid in locating causes of streaks.

(Manuscript received September 29, 1952.)

* One N.B.S. unit of color difference is barely discernible by the eye.

Textile Education and the Challenge of the Future*

Martin J. Lydon†

It may properly be stated that the challenge faced by textile education in the future can be defined simply as the task of preparing young people to recognize, analyze, evaluate, and attempt to solve specific problems. I believe that all of us recognize the fact that education is a continuing process which goes on whether we are in school or out. The school, then, is conceived as the formal agency of society which is charged with the responsibility of giving a definite program of training for specific purposes. In this sense, it polishes certain facets of the student's personality, and in this task it is supplemented by other social agencies, such as the home, the church, business, and industrial organizations. As a specialized institution with a specialized task, the school is faced with the problem of deciding just where to begin and where to end in doing its job. The beginning usually is arbitrarily decided by tradition and custom, but the end has been, in recent years, increasingly advanced in point of time until now the formal educational institutions offer services of one type or another to all age groups and to all areas of social, political, and economic interest.

Thus, education is big business. In view of the magnitude of its task and the breadth of its scope, it is not easily subject to appraisal and evaluation, and, therefore, let us consider here only the work of *higher* education as it relates to the field of textiles. This is not to slight the very commendable work done on the secondary school and vocational school level, and it is not by any means to minimize the importance of the very valuable and significant educational job done through apprenticeship, on-the-job training, and other programs; it is simply to restrict our sphere of consideration to a relatively confined area which lends itself to critical scrutiny.

Functions of Educational Institutions

There are at least three basic functions of institutions of higher learning: the transmission of knowledge, the increase of knowledge, and the interpretation of knowledge. Let us consider each of these in turn. The transmission of knowledge is the most elemental task of colleges and universities, and in its simplest form really means the transfer of information from past generations to the present. In discharging this first function, the present textile schools and colleges have always been efficient and effective. In this country most of the textile schools and colleges came into being some 50 years ago, and were founded upon an educational philosophy which pretty well limited their basis of operation to the simple transmission or transfer of knowledge. Until recently, these schools attempted primarily to give their students a working knowledge of basic fibers and basic operations. This program was sufficient in the past because the textile industry had not changed in any marked degree for generations, and the simple transmission of the knowledge of the past was adequate for the purposes of the time. The developments and innovations of the last few years, however, have made this educational philosophy outmoded and inadequate. The newest developments in the sciences and their applications to the textile industry have made it imperative that the emphasis of textile education be redirected. The objectives of textile education now must be changed to give the student breadth in his knowledge and point of view so that he will understand the scientific and engineering principles upon which textile technology is based, preparatory to learning the further applications of these principles in industry and research. In other words, it is no longer sufficient to understand *how* a thing is done; it is imperative that one understand *why*. Thus, the transmission of knowledge becomes an increasingly difficult chore.

Industry in general and the textile industry in particular will undergo such cataclysmic changes in the future that it would be folly to attempt to train young people for the present only. It is necessary to prepare them for the complexities and uncertainties of the future. If young students were to be taught only how to solve current problems, they would be behind the times before they were graduated. It is impossible to calculate now exactly what products and processes will characterize our economy 10 years hence. However, it is definitely certain that industry

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† President, Lowell Textile Institute, Lowell, Mass.

in the next decade will need men trained for leadership. Industry must have men whose education has been such that they can recognize, appreciate, and correlate a galaxy of problems in such diverse areas as chemistry, personnel relations, and production engineering; this means broadening our educational base so that tomorrow's leaders will have an understanding of many different fields of thought. Industry must have men in executive positions who know where to look for help in solving problems which are beyond the range of their own capabilities, and in securing this help they must have the ability to define their problems in sufficiently specific terms to ensure securing the results which they are seeking. In this connection, there is a particular point to be made with respect to the matter of educating for leadership. It must be remembered that when we talk in terms of leadership we are talking also in terms of specialization, because leadership is an outgrowth of competence in one's field, and competence can come only through specialization. Thus, at the same time that educational institutions are giving a minimal foundation to the students in the form of courses in the basic sciences and other subjects, it is necessary also to include those studies in special fields which give direction and meaning to the student's preparation for a career. In other words, specialization on the undergraduate level is necessary to implement and integrate the theoretical fundamentals with the applications to be anticipated in one's major life work. This means that in transmitting knowledge, the instruction must be geared to the individual student; it must be calculated to give him the optimum preparation for his career of leadership. It means also that the better students must be given every opportunity to exploit their superiority so that they will strike off on their own into new ways of thinking. They will not be satisfied merely to absorb the knowledge transmitted from the past, but will wish to supplement the thinking of others with original concepts and ideas of their own. Institutions of higher learning thus not only prepare their students to *meet change*, but also prepare them to *make changes*—to plan, initiate, and promote new developments. This is the hallmark of leadership. This is progress.

Integrating Education with Research

So, we come to the consideration that the first function of educational institutions—the transmission of knowledge—basic as it is to human progress, nevertheless adds nothing to total knowledge. Therefore, it is mandatory that whenever we speak in terms of the first function we must also integrate with it the second function; thus, the research which increases knowledge becomes one of the most important elements in education. In actuality, research and education are really just two sides of the same coin. This is illustrated by the fact that some institutions which heretofore have been concerned primarily with instructional activity are now doing an increasing amount of research, and many institutions which have formerly been concerned primarily with research now undertake instructional programs. This is good, for the closer the integration between these two complementary activities, the greater will be the increase of knowledge placed at the disposal of the industry and society at large.

Research no longer needs to be "sold." Education, industry, and the general public are acutely aware of the fact that much can be expected of this type of work. The publicity which has been given to research in recent years has allayed the fears of those who were inclined to question the money, time, and energy devoted to such investigations. It may even be that research has been *oversold* and *overpublicized*, because it is now regarded by many as a kind of magic pill which will cure all the ills of industry, government, and society. It might fairly be stated that it is not research *itself* which needs to be sold, but rather it is the proper *use* of research which should be sold. The completeness and effectiveness with which the results of the research work are used are the final criteria for determining the success of any research program. This fact tends to point up some of the basic reasons why educational institutions are uniquely valuable for securing proper results from research. The educational institution, unlike industry, is not particularly dismayed if the results of the research are not germane to the objectives stated in the first inquiry or proposal. There are several reasons for this: (*1*) All research results are utilizable for educational work whatever the findings, and conclusions secured from research can be used in some manner to illustrate or explain the facts and truths which are part of the first function of the institution of higher learning, the transmitting of knowledge. (*2*) Every new conclusion, no matter how unrelated to the original reasons for the investigation, is an increment in swelling the sum total of the second function of education, the increase of

knowledge. (*3*) The educational institution is happy to have its student body and its faculty undertake inquiries in their special field of interest, because by so doing they secure valuable experience, training, and new ideas and points of view. (*4*) In pursuing such fundamental research programs, the schools and colleges tend to become the repositories of vast stores of knowledge, and as such they become important sources of information to which industry and the community may turn as occasion demands. (*5*) The diverse talents of the personnel and the plethora of various types of equipment and machinery tend to make the textile schools and colleges particularly versatile and facile in undertaking research programs. It must be pointed out, however, that basic research is still relatively rare, even in the schools and colleges; certainly it should be encouraged to grow in both quality and quantity.

The educational institution may very well be willing to engage in a long-term project, the precise results of which may long be in doubt, but industry is not in such an advantageous position. Some of you may recall a cartoon in the August, 1952, edition of *Textile World;* the cartoon depicts two research workers side by side with one saying to the other, "I've been on this research so long I've forgotton what I'm supposed to be trying to discover." Industry cannot long support such activities. It must know what it wants to get and how long it will take to get it. This suggests again two points which I have previously mentioned in connection with the transmission of knowledge. First, men in industry must be sufficiently broad to understand the diverse problems which confront them so that they will know how and where to look for their solution; and, second, they must be sufficiently specialized in particular areas to be able to define for themselves and for others exactly what the problem is which must be solved. Thus, not only are the textile school and college particularly important as agencies for the *transmission of knowledge,* but they are also very effective agencies for *developing the research point of view*—not only for future researchers, but also for the future leaders of management. The educational institution thereby becomes a most important factor in the two-way flow of data between research and industry. In a sense it might be said that the educational institution is the common denominator between research and industry. The institution of higher learning does research work itself and thereby trains researchers who will ensure a perpetual flow of new ideas, discoveries, and inventions. At the same time, the textile schools and colleges educate young men for leadership in management to bring to fruition the ideas of the researcher. This twofold activity cannot fail to succeed in conditioning both elements—research and management—to complete understanding and cooperation in the pursuit of their mutual goals. This sympathetic appreciation for each other's problems and capabilities is of the utmost value in effectuating good results.

The stategic position of the institution of higher learning can be further illustrated in another way; the college or university which undertakes both fundamental and applied research is in a most advantageous position to correlate and integrate both types of work. Moreover, institutions of higher learning not only are midway between the theory and the industrial applications of research, but they also are in a particularly strategic position to make known to the general public the type of work carried on by industry and by the various educational institutions themselves. In this connection, it may fairly be said that the matter of making known the results of research has long been a topic for confusion, consternation, and conflict. Almost all industrial processes have been subjected to a certain secretiveness, which is quite understandable. By making known the results and products of research, I do not mean in any sense to suggest disposing of this secrecy, a certain amount of which is necessarily a part of our competitive free enterprise economy. I do feel, however, that there is much to be done in changing the attitude of the general public and, indeed, of some elements of industry with respect to the principal characteristics of research activity. The attitude of the general public may be dramatized by describing an incident which occurred last fall at the registration of students at a certain evening textile school. A mail girl from one of the local cotton mills expressed a desire to register, and requested information concerning the various types of courses. The registrar said, "What course do you wish to take?" The girl replied, "I want to do research." The registrar naturally asked, "What kind of research?" To which the girl replied, "I don't care, just research." This certainly would seem to indicate a slight misconception of the nature and function of research. The feeling on the part of some segments of industry may perhaps be summarized by the view of many industrialists that research is an activity conducted in a vacuum by men

and women who live in a pleasant dreamworld untroubled by reality. Very often, too often, some managements feel that research is a luxury—something to be eliminated, or at least diminished, whenever their economic position worsens, when perhaps the opposite action should be taken.

I should like to argue for a more realistic view of the potentialities and capabilities of research, so that disappointments will not be so likely, and in order that there may be a sustained support for research activity—a support based upon real faith in research work. The achievement of such a goal means that in order to secure a realistic view of what research can and cannot do, the general nature of research techniques and procedures must be indicated and the purposes, philosophy, and objectives of research must be explained in concrete and specific terms. Here again, the educational institution assumes a role of prominence and service, because the educational institution in performing its first function—transmitting knowledge—is in the best possible position to make known to industry and to the general public the truly effective role that research can play in the world of the future.

Interpretation of Knowledge

Thus we come to the third function of institutions of higher learning—the interpretation of knowledge. It is commonplace to observe that with the increase in the volume of knowledge, and with the increase in the complexity and multiplicity of the issues of the day, the need for the proper interpretation of knowledge becomes more acute and the role of the interpreter of knowledge becomes more significant. The interpreter is, of course, he who transmits knowledge and he who increases knowledge, for the two are in most instances identical. The instructor and the researcher, therefore, become two of the most important cogs in the development of our civilization. It is their task to inspire, to motivate, and to direct succeeding generations of young people to accept the challenges of problem-solving so that industrial, social, and cultural progress may be sustained. It has been said that truth is revealed; it needs only to be practiced. The institutions of higher learning are particularly suited to stimulate and to inspire the implementation of the knowledge which they interpret. Such intangibles as the research attitude and belief in the free enterprise system, such ethical factors as integrity, honesty, dependability, and similar characteristics are developed in young people by those who interpret knowledge in our schools and colleges. Of course, it must be admitted that such institutions cannot do the job alone; but they can do a good deal, and I am sure that all will agree that these attitudes and attributes are absolutely necessary if industry is to have the qualities of leadership which are so necessary to sustain its progress and prosperity.

The textile schools and colleges are ideally positioned to combine theory and practice, not only with regard to the technology of the machines but also with respect to the great truths of human civilization. This means that our institutions of higher education must continue their efforts to arrange their curricula so as to provide for the inclusion of courses in humanities and social studies, what the engineer has been calling during the last few years the "socio-humanistic stem"—this means studies of history, communication, psychology, sociology, and related areas of interest. Only a few short years ago these areas were considered to be completely out of place in the offerings of technological and engineering colleges. Now, however, largely at the insistence of the industries which these colleges service, these subjects have become an integral part of the college curriculum. Industry more and more has come to realize that some of its most important and pressing problems have to do with human relations. It has become increasingly apparent that good men are not able to exploit their talents and abilities unless they are able to get along with other people. In other words, it seems quite agreed by educators and industrialists alike that one's best thinking is not of any use unless it is accepted by others. Prominent men in industry are saying that education should train scientifically and technologically sound men for executive positions —men who can understand and define problems—scientific, technological, and human. The textile schools and colleges have been taking their cue from this observation. They are developing in their students an understanding of scientific and technological know-how, together with a facility for getting along with others. The increasing complexity of our economic and social life demands an ever higher understanding of the environmental problems which we face every day. The schools and colleges are in an excellent position to supply this understanding. Understanding why one does something is the first step in understanding why one's fellow acts as he does. Similarly, understanding the truths of the past is the

first step in understanding what to expect in the future. In effect, the educational institutions may be likened to a bridge between the past and the future, in which all of the elements of living are made an integral part of the curriculum.

Textile schools and colleges by integrating all of the various types of human knowledge, by transmitting them and by increasing them, as well as by interpreting them, prepare youth to face the challenges of the future. In other words, the institutions of higher learning, whether in textiles or in any other field, serve as a cynosure upon which the knowledge of the past, the facts and realities of the present, and the inevitable problems of the future are brought into focus and are made understandable and meaningful to successive generations.

Meeting the Challenge of the Future

The schools and colleges which have sponsored textile education have succeeded in the past to a remarkable degree. Indeed, during the recent period of rapid transition in the industry, they have done an excellent job in preparing their graduates for the changes which have recently taken place. There is no doubt in my mind that in the years ahead industry will experience even greater and more far-reaching innovations, modifications, and dislocations; and in anticipation of this eventuality I should like to suggest that immediate steps be taken so that industry and institutions of textile education may prepare themselves and the community for the changes which must come if we are to have continued industrial and social progress. Thus, I should like to suggest four recommendations which I believe will be in the best interests of the educational institutions, of industry, and of the economy at large.

In the first place, I should recommend the institution of exchange professorships among the various textile schools and colleges. This exchange program would make possible a community of interest among the various institutions and would tend to stimulate new ways of thinking and doing things in so far as different points of view are brought from other institutions.

A second recommendation would be the granting of academic leaves of absence within institutions to enable instructors and professors to leave their regular teaching schedule for a year or more in order to devote their full attention to research. The advantages of such a program would be multiple. Not only would the professors be refreshed by leaving their classroom routines for a period, but also they would find inspiration in delving into research problems of particular interest.

A third recommendation is that industrial leaves of absence be given in two ways. The first is from industry to education; industry would permit selected personnel to take leaves for various periods of time in order to join temporarily the staffs of educational institutions and thus bring the industrial point of view to the schools and colleges which are training the industrial executives of the future. The second way in which the industrial leaves of absence could operate is the opposite to that just outlined—namely, leaves of absence from education to industry. Men presently on the staffs of textile schools and colleges would be given temporary leaves to take positions with industry, thereby picking up the industrial point of view but picking it up "on the spot," so to speak.

The fourth and final recommendation is that the integration between education and industry be implemented and accelerated by the mutual exchange of ideas and conclusions at meetings, conventions, assemblies, and joint symposia, as well as in the technical literature and publications by industrial, educational, and other agencies. I firmly believe that the interchange of ideas and the cross-fertilization of thinking is one of the most important things upon which our future industrial prosperity will be based. I believe that there is a great deal which the institutions of higher learning can do to stimulate this exchange of ideas, and I frankly feel that it is the textile schools and colleges which should take the initiative in sponsoring such thinking. If the institutions of higher learning are best able to accomplish the results which I have attributed to them, then certainly they are best able to take the necessary steps to prove to industry and to the community in general just how good they are.

I believe that if these four recommendations are followed, the challenge which the future poses for textile education will be met with real success. The challenge is simply to define, to analyze, to evaluate, and to solve problems—specific problems. Problem-solving is an art, no matter the kind of problem involved, but no problem can be solved without the will to solve it, and it is precisely in this connection that the schools and colleges can perform a service

which no other organization or element of society can do with the same efficiency and effectiveness. Ethical consideration of such intangible attributes as pride in ownership, pride in accomplishment, and personal integrity all can be stimulated in institutions of higher education, as the student learns how to meet the everyday problems of industry and society with dispatch, thoroughness, and enthusiasm. The textile industry has a great future, but it is fraught with complicated problems. The only way in which the future can be realized to the full is through the enlightened and humanitarian leadership of intelligent men and women. The textile schools and colleges are turning out just such graduates—people who have been exposed to those elements of instruction and inspiration which are the very gist of progress. In these institutions of higher learning the best precepts of education and the most courageous concepts of research are integrated and articulated through the transmission, the increase, and the interpretation of knowledge. The succeeding generations of young students in these textile schools and colleges are being taught the very basic fundamentals of science, technology, and the American way of life. Textile education has every reason to be proud of its past, confident of its present, and optimistic of its ability to meet the challenge of the future.

(Manuscript received November 24, 1952.)

Book Reviews

Microbial Decomposition of Cellulose. Ralph G. H. Siu. New York, Reinhold Publishing Corp., 1951. 531 pages. Price, $10.00.

(Received by Edward Abrams, Southern Research Institute, Birmingham, Ala.)

During the recent war the need for protecting cellulosic materials from attack by mildew was emphasized by our campaigns in the South Pacific. Very little in the way of information or of protective materials was available at the beginning of the war. It can safely be stated that the significant contributions to the field of prevention of deterioration of cellulosic materials have been made since 1941. Dr. Siu and his coworkers at the Pioneering Research Laboratories of the U. S. Army Quartermaster Corps have made many important contributions to this field since that time.

In this book, Dr. Siu summarizes all of the work which was carried on in his laboratory and elsewhere during the past 10 years. Much of this work has not been published before.

The book is well organized and begins with a discussion of cellulose decomposition in nature. The significance of the carbon cycle is developed along with the economic aspects of the problem. Following this is a section on the structure and properties of cotton fabrics. Although the title implies that this book is a study of cellulose decomposition, Dr. Siu has preferred to concentrate on cotton, which, of course, is the purest form of cellulose. In this section are discussed the physical and chemical properties of the cellulose molecule, as well as the features of cotton fibers.

The next section gives a very complete discussion of the organisms responsible for the degradation of cellulosic materials. The next section contains a discussion of the mechanism of degradation by microorganisms. The gross aspects of degradation of fabrics are described; these include staining and discoloration, loss in strength and weight, and the microscopical appearance of damaged fibers. The biochemical transformation of cellulose molecules is also discussed. The degree of crystallinity of the cellulose is related to its microbiological susceptibility. The enzymes involved are discussed, as are the energy requirements for molecular cleavage. This section concludes with an excellent statement in diagrammatic form of the present concept of the degradation mechanism.

The final section is concerned with methods of prevention and with methods for testing microbiological resistance of treated cotton textiles. It is complete and up to date. There are excellent reference lists at the ends of the chapters. The value of the book is further enhanced by an author index, a microorganism index, and a subject index.

Dr. Siu is to be congratulated for writing the right book at the right time.

Die neuzeitlichen Textilveredlungsverfahren der Kunstfasern. Vol. XX. F. Weber and A. Martina. Vienna, Springer-Verlag, 1951. 786 pages. Price, $32.00.

(Reviewed by P. M. Levin, E. I. du Pont de Nemours & Co., Wilmington, Del.)

This book was written to fill gaps in the man-made fibers literature collections in Europe as a result of World War II. But, even if it didn't have this useful purpose, with its underlying comment on the destructive effects of war on technical communication, the book would still be a valuable reference.

The authors have covered literature and patents from 1939 to 1949, including part of 1950 in some instances. It was during this period that some of the most rapid progress was made in the production and processing of man-made fibers. To cover this period, the authors devoted about 125 of the book's 700 pages to the chemistry and manufacture of man-made fibers; successive sections review bleaching, dyeing, printing, finishing, and the preliminary treating of textiles, in that order. The section on printing is unusually large, considered from the American standpoint, but reflects the greater use of printing in Europe.

Each section is subdivided according to fiber type, where such a subdivision is applicable, or is subdivided according to process type, where a single process has been applied without change to a number of different fiber types. For example, the section on bleaching is broken down into various bleaching processes. The section on dyeing is first subdivided into fiber types and then into dye types.

Each subdivision consists of a summary followed by a literature bibliography and then patent references. The usefulness of the literature bibliographies is somewhat limited by the fact that they contain only authors and references, without any indication of content other than the heading of the subdivision which the bibliography follows. Then, too, the scope of the bibliographies seems to be somewhat limited. On the other hand, the patent references are more useful. Patents are given by country, number, assignee, date of issue, and a brief descriptive sentence. A cursory check of American patents on the production of man-made fibers showed that important patents are covered this way. Patents that the authors consider to be of less importance are mentioned solely by number. Even if some omissions may later be found, the wide geographical coverage of patents should prove very valuable. As far as we know, no other similar collection as thorough as this one exists for this period.

The number of typographical errors seems to be about average, considering the material in the book. What are hoped to be most of the errors, including those in patent numbers, are collected on an errata sheet. However, in the footnote on p. 46 the formula for converting g/100d into rkm is wrong; it should be expressed as g/100d $\times$ 0.09 = rkm. Other errors noted were misspellings that would not mislead the reader.

The book also contains a subject index and a patent number index.

Förädlad Textil (Finished Textiles). Aktiebolaget Alf Stigens Fabriker. Sandared, Sweden. 1951. 174 pages.

(Reviewed by Jan Linderot, Swedish Institute for Textile Research, Gothenburg, Sweden)

Published by one of Sweden's leading dye works on the occasion of the twentieth anniversary of the founding of the company, this book surveys the history and development of the art of dyeing textiles. Many facts and features of dyeing techniques from the early Asian cultures to modern times are revealed. It is interesting to note how a well-developed dyeing technique is connected, as a rule, with a flourishing cultural life, and how this technique degrades during the decline of that civilization. It is also remarkable how little progress was made following the early developments until the middle of the nineteenth century. Then came the development of the coal-tar dyes, which completely changed the picture. Of that fascinating story the book tells very little.

Part of the book gives details of the development of dyeing in Sweden, including a description of modern dyeing and finishing processes, and ends with a short account of some of the specialties of the Stigen Company.

It is unfortunate that the book is written in Swedish. However, the profusion of illustrations, many of them from old woodcuts, together with the inclusion of a supplement containing translations of the captions to the pictures, makes the book of value to all persons interested in the historical development of textiles.

It is understood that a limited number of copies are available without charge to institutions and libraries. They may be had by writing to AB Alf Stigens Fabriker, Sandared, Sweden.

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